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Report No. F/Res/237

February 1954

MARINE AIRCRAFT EXPERIMENTAL ESTABLISHMENT, FELIXSTOWE, SUFFOLK.

INVESTIGATION OF HIGH LENGTH/BEAM RATIO SEAPLANE HULLS WITH HIGH BEAM LOADINGS

HYDRODYNAMIC STABILITY PART 3

THE STABILITY AND SPRAY CHARACTERISTICS OF MODEL A

by

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S U M M A R Y

In this report results are presented of tests on the hydrodynamic characteristics of Model A, the basic model of the series. This model has a length/beam ratio of 11 (the forebody being 6 beams in length and the afterbody 5 beams), an afterbody to forebody keel angle of 6°, and a straight transverse step with a step depth of 0.15 beams; it has no warp and no step fairing.

The tests comprised the determination of longitudinal stability limits without slipstream at C_{Δ_o} = 2.75 and 3.00, an investigation of spray at these loadings, and an assessment of directional stability at C_{Δ_o} = 2.75, which covered the effects of attitude, roll constraint and breaker strips. A short discussion of the results is also included.

Addendum to M.A.E.E. Report No. F/Res/237

Figure 11 should be disregarded, as subsequent measurements have shown the formula used to be somewhat inaccurate.

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/ 1. INTRODUCTION

1. INTRODUCTION

In this report results are given of tests on the stability and spray characteristics of Model A of the series detailed in Reference 1, a list of which is reproduced in Table I. Model A, as the first model of the programme, was designed with no hydrodynamic refinements and is the basic model on which changes of the various hull parameters have been made. It has a length/beam ratio of 11 (the forebody being 6 beams in length and the afterbody 5 beams), an afterbody to forebody keel angle of 6°, and a straight transverse step with a step depth of 0.15 beams; it has no forebody warp, no effective afterbody warp and no step fairing. Full details are given in Reference 1 of considerations affecting the design of the models, but hull lines and photographs of this model are given in Figures 1 and 2 respectively, while hydrodynamic and aerodynamic data are given in Tables II and III. The techniques used in the tests and the presentation of results, together with the reasons for using them, are considered in References 1 and 2, though a brief summary is given in the next section.

The tests performed included the determination of longitudinal stability limits at C_{Δ_0} = 2.75 and 3.00 without slipstream, of the spray characteristics at these values of C_{Δ_0}, and an assessment of directional stability for C_{Δ_0} = 2.75, with no roll constraint at high and low attitudes, with roll constraint at high and low attitudes, and with roll constraint and breaker strips at high attitudes.

Figures are included showing the limits and there are a number of subsidiary diagrams. Where possible results have been presented non-dimensionally.

2. DESCRIPTION OF TESTS

2.1. General

All tests were made with one C.G. position, no slipstream, zero flap and at steady speeds only. The pitching moment of inertia of the model was 22.90 lb.ft.^{2} in all longitudinal stability tests.

2.2. Lift

Lift runs were made at constant speed with the model clear of the water, over a range of attitudes with $\eta = 0°$. A limited number of these runs were repeated at a different speed to check Reynolds Number effects, and the effect of elevator was determined at four attitudes. The resulting curves are given in Figure 3.

2.3. Longitudinal Stability

Longitudinal stability tests were made by towing the model from the wing tips on the lateral axis through the centre of gravity, the model being free in pitch and heave. The value of the elevator setting was selected before each run, and the model towed at constant speed. The angle of trim was noted in the steady condition, and if the model proved stable at the speed selected it was given nose-down disturbances to determine whether instability could be induced, the amount of disturbance given to cause instability being in the range of 0-10°. The larger amounts of disturbance were required near the undisturbed lower limit at high speeds. Stability limits were built up by these methods, the disturbed limits representing the worst possible case. Tests were carried out with C_{Δ_0} = 2.75 and 3.00, and the corresponding trim curves and stability limits are given in Figures 4 - 7. The limits for the different values of C_{Δ_0} are plotted together in Figures 9 and 10 for

comparison on a C_V base and the undisturbed lower limits, transposed to a draught base by the formula of Reference 1 for the equivalent wedge, are plotted in Figure 11; Figures 12 and 13 are subsidiary curves necessary for this transposition.

When steady porpoising occurred, either with or without disturbance, the amplitude was noted, amplitude for this purpose being defined as the difference between the maximum and minimum trims attained in the oscillation. These amplitudes are plotted in Figures 14 and 15, for the various cases concerned.

In addition to the limits obtained with maximum disturbance, partial limits for different fixed degrees of disturbance were obtained and they are shown in Figure 8.

2.4. Spray and Wake Formation

Photographs were taken of the spray, from three different positions, over a range of speeds and with elevators set at -8°. A number of these photographs are reproduced in Figures 17 to 20. They have been used to determine the projections of the spray envelopes on the plane of symmetry of the model at the different values of C_{Δ_0}, and these projections are plotted in Figure 21. This method of plotting differs from that originally proposed (Reference 1) but is felt to be more realistic. The absence of projections orthogonal to these, which cannot be obtained from the photographs, is not serious since the photographs enable the positions of the spray blisters to be judged qualitatively, and in any case the curves are intended for comparison purposes rather than for absolute measurements. It should be noted that in plotting the projections velocity spray has in general been ignored.

In addition to the spray photographs, photographs of the wake region for $C_{\Delta_0} = 2.75$, were taken from two different positions and are reproduced in Figure 16. These photographs covered a range of speeds and elevator settings, the combinations being selected to give the maximum possible variation of wake formation and position relative to the afterbody in the stable planing region.

2.5. Directional Stability

In the directional stability tests with no constraint, the model was pivoted universally at the C.G. so that it was free in pitch, roll, yaw and heave, limits being applied in roll only to prevent the wing tip boxes from submerging. The model was towed from the C.G. and moments to yaw the model were applied by means of strings attached to the wing tips and in the same horizontal plane as the C.G.

For the low attitude directional assessment steady speed runs were made with the elevators set at +2°, the model being yawed up to not more than 18° and the values of yaw giving equilibrium determined by the operator by assessment of the direction of the resulting hydrodynamic moment on the model. The directional stability diagram so obtained is plotted in Figure 22. For the high attitude case these tests were repeated with elevators set at -10°; the results are shown in Figure 23.

For the directional stability tests with roll constraint, freedom in roll was completely restricted and the runs carried out as before with elevators at +2° and -10° for the low and high attitude cases respectively (Figures 24 and 25). The tests with breaker strips[1] were done in a similar manner, with roll constraint, elevators set at -10° and the optimum strip arrangement, which was found after some experimenting. Results are plotted in Figure 26.

/ Throughout

Throughout these tests the value of C_{Δ_0} was 2.75, and in all cases the occurrence of very high drag forces at large angles of yaw and high speeds made it impossible to investigate some regions.

2.6. Elevator Effectiveness

Curves of elevator effectiveness calculated from the longitudinal stability diagrams are given in Figures 27 and 28.

3. DISCUSSION OF RESULTS

The lift curves (Figure 3) have no irregularities and show clearly the effect of elevator, which is considerable.

The longitudinal stability of the model is poor. In the undisturbed case there is, at the lower weight, an unstable band extending right across the diagram, just after the hump (Figure 4). The effect of increased load (Figures 6 and 9) is to widen this unstable band by 50%, increase the hump trim, which is already high at 11.7°, by about 0.3° and raise the lower limit by almost double this amount; the upper limit is raised slightly. The lower trim curves are raised substantially in the planing region, but this effect decreases progressively with increase in attitude, by about half at the higher trims.

The effect of disturbance in the lower weight case ($C_{\Delta_0} = 2.75$) can be seen by comparing Figures 4 and 5. There is a marked deterioration in stability, the unstable region now covering most of the diagram. From Figure 8 it will be seen that relatively large disturbances are necessary to induce instability in the high speed lower limit region, but once started the porpoising is violent, the model leaving the water during each cycle (Figure 14) and, although the limits of Figure 8 are only partial, it is apparent that only relatively small disturbances are necessary to cause instability in the mid-planing region; once instability starts however, porpoising amplitudes are still large. In the regions where porpoising occurs undisturbed, the effect of disturbance is to increase the amplitudes greatly, particularly along the undisturbed lower limit.

The effect of disturbances in the higher weight case ($C_{\Delta_0} = 3.00$) is similar (compare Figures 6 and 7 and see Figure 10). Stability deteriorates markedly and porpoising amplitudes increase (Figure 15), becoming severe in the high speed lower limit region. The undisturbed limits for the two weights are compared in Figure 10 and it can be seen that the effect on the limits of increasing load is roughly double what it is in the undisturbed case.

The two undisturbed lower limits have been transferred to a draught base (Figure 11) by the formula derived in Reference 1. The load effect on draught at these limits is small and nearly constant, instability occurring, at a given attitude, at a greater draught for the lower weight.

The load coefficient curves of Figures 12 and 13, which are used in transposing the limits to a draught base, can be used to estimate flying speeds, but it should be noted that no allowance has been made in them for ground effect.

Photographs of flow in the wake (Figure 16) at the lower weight, are included to show the position of the afterbody relative to the wake in representative positions. Association of these flows with instability can be investigated by reference to Figures 4 and 5. Figure 16(a) shows a typical high attitude, low speed planing case. The afterbody is planing and at this setting the model becomes unstable for small disturbances, two step porpoising resulting. In (d) the low attitude, low speed case is given;

/ the

the afterbody is well clear of the wake, but with small disturbances instability results. Case (c) is in the mid-planing region; the afterbody is again clear of the wake and the model becomes unstable for disturbances of 5^{o} or more, i.e. greater than (a) or (d). The high speed end of the stability diagram is represented by photographs (b) and (e) for high and low attitudes respectively. In (b) the aft step is just touching the wake and in this configuration the model is stable for all disturbances, while in (e) the aft step is well clear and violent forebody instability is induced with a minimum of 5^{o} disturbance (Figure 8), the model leaving the water during each cycle.

Figures 17 - 20 show the spray formation at two weights, with one elevator setting, mainly over the displacement range of speeds. The spray characteristics of this model are mediocre, spray hitting the underside of the wing in three of the cases at each weight, while the tail plane is at all times well clear; jet intakes would not be affected, but propeller tips probably would be. The effect of weight change is shown in Figure 21, but it is not significant.

Details of the interpretation of the type of directional stability diagram used have already been given in Reference 1, so only the effects of change of attitude, roll constraint and breaker strips will be considered.

The attitude in pitch of the model is governed by the elevator setting, which was kept constant throughout the speed range. Two elevator settings were chosen to give extremes of trim within the stable undisturbed region. It may be pointed out that, at a given speed, elevator and attitude are synonymous if the restriction to a working attitude range is made, as it is here. Comparing Figures 22 and 23, the only effect of attitude change with no roll constraint is to move the high speed unstable equilibrium line by a small amount. This effect would not be significant in a practical case and does not warrant separate investigation. It is of similarly small order when the roll constraint is introduced (cf. Figures 24 and 25) and is still limited to the high speed end of the diagram. The effect of roll constraint can be seen at low and high attitudes by comparing Figures 22 and 23 with Figures 24 and 25. In both cases the effects are relatively small; there is again a small displacement of the high speed unstable equilibrium line and at lower speeds, $C_V = 4$ and 5, roll constraint causes the unstable equilibrium line to be moved nearer to the stable one. The whole diagram is thus radically similar in form. By comparing Figures 25 and 26 the main effect of breaker strips[1] will be seen to be to remove the outer high speed equilibrium lines (above $C_V = 3$). As no additional information is obtained this type of test has been discontinued. It is interesting to note that with breaker strips, heavy porpoising occurs above $C_V = 7$, where it does not occur without. It is suggested that as the reaction between the flow and the strips cannot yaw the model, because the angle of yaw is maintained by the operator, it manifests itself by a nose down movement in pitch, which is tantamount to a disturbance and so the disturbed type of instability, which is severe, sets in. Tests with various numbers and positions of breaker strips showed the high speed directional instability to be due to hydrodynamic suctions over a small area of the afterbody side near the rear step.

Future directional stability tests will thus be done at one weight,[1] with one elevator setting (a low attitude one) and roll constraint.

The plots of elevator effectiveness in Figures 27 and 28 show that effectiveness decreases with increase of load, the effect being more pronounced at $C_V = 7$ and 8 than at the other speeds considered.

/ 4. CONCLUSIONS

4. CONCLUSIONS

The tests performed indicate that this hull has mediocre hydrodynamic properties in calm water, and very poor ones in rough water. The spray characteristics are also indifferent. For these reasons the choice of this hull form as the basic one for the series is good; its characteristics may be said to lie near the middle of the quality range and the effect of changing any hullparameter will easily be seen.

LIST OF SYMBOLS

b	beam of model
d	draught
C_L	lift coefficient = $L/\frac{1}{2}\rho\ SV^2$ (L = lift, ρ = air density)
C_V	velocity coefficient = $V/\sqrt{gb}$
C_Δ	load coefficient = Δ/wb^3 (Δ = load on water and w = weight per unit volume of water)
C_{Δ_0}	load coefficient at V = 0
C_X	longitudinal spray coefficient = x/b
C_Y	lateral spray coefficient = y/b
C_Z	vertical spray coefficient = z/b
	$\{$ (x,y,z) co-ordinates of points on spray envelope relative to axes through step point $\}$
S	gross wing area
V	velocity
α_K	keel attitude
η	elevator setting
ψ	angle of yaw

/ LIST OF REFERENCES

LIST OF REFERENCES

No.	Author(s)	Title
1	D.M. Ridland J.K. Friswell A.G. Kurn	Investigation of High Length/Beam Ratio Seaplane Hulls with High Beam Loadings: Hydrodynamic Stability Part 1: Techniques and Presentations of Results of Model Tests. M.A.E.E. Report F/Res/232. September 1953.
2	J.K. Friswell A.G. Kurn D.M. Ridland	Investigation of High Length/Beam Ratio Seaplane Hulls with High Beam Loadings: Hydrodynamic Stability Part 2: The Effect of Changes in the Mass, Moment of Inertia and Radius of Gyration on Longitudinal Stability Limits. M.A.E.E. Report F/Res/233. September 1953.

/ TABLE I

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TABLE I

Models for hydrodynamic stability tests

Model	Forebody warp	Afterbody length	Afterbody-forebody keel angle	Step form	To determine effect of
	degrees per beam	beams	degrees		
A	0	5	6	Unfaired transverse. Step depth 0.15 beam.	Forebody warp
B	4	5	6		
C	8	5	6		
D	0	4	6		Afterbody length
A	0	5	6		
E	0	7	6		
F	0	9	6		
G	0	5	4		Afterbody angle
A	0	5	6		
H	0	5	8		

/ TABLE II

TABLE II

MODEL A - HYDRODYNAMIC DATA

Beam at step (b)	0.475'
Length of forebody (6b)	2.850'
Length of afterbody (5b)	2.375'
Angle between forebody and afterbody keels	6°
Forebody deadrise at step	25°
Forebody warp (per beam)	0°
Afterbody deadrise	30°
	(decreasing to 26° at main step over forward 40% of afterbody length).
Pitching moment of inertia	22.90 lb.ft.^{2}

/ TABLE III

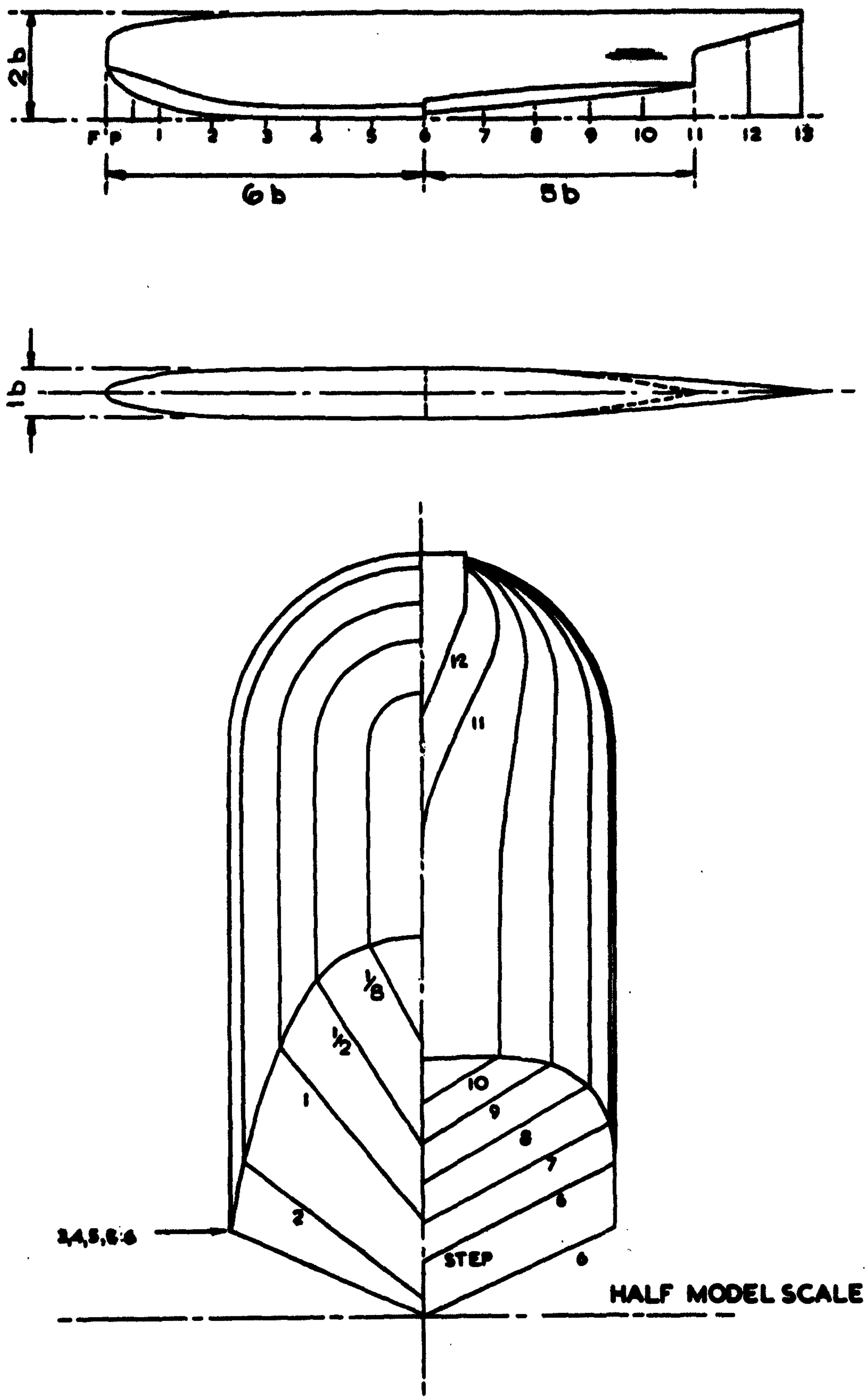
TABLE III

Model Aerodynamic Data

Mainplane	
Section	Gottingen 436 (mod.)
Gross area	6.85 sq. ft.
Span	6.27 ft.
S.M.C.	1.09 ft.
Aspect ratio	5.75
Dihedral } on 30% spar axis	3° 0'
Sweepback } on 30% spar axis	4° 0'
Wing setting (root chord to hull datum)	6° 9'
Tailplane	
Section	R.A.F. 30 (mod.)
Gross area	1.33 sq. ft.
Span	2.16 ft.
Total elevator area	0.72 sq. ft.
Tailplane setting (root chord to hull datum)	2° 0'
Fin	
Section	R.A.F. 30
Gross area	0.80 sq. ft.
Height	1.14 ft.
General	
* C.G. position	
distance forward of step point	0.237 ft.
distance above step point	0.731 ft.
* $\frac{1}{4}$ chord point S.M.C.	
distance forward of step point	0.277 ft.
distance above step point	1.015 ft.
* Tail arm (C.G. to hinge axis)	3.1 ft
* Height of tailplane root chord L.E. above hull crown	0.72 ft.

* These distances are measured either parallel to or normal to the hull datum.

FIG. 1



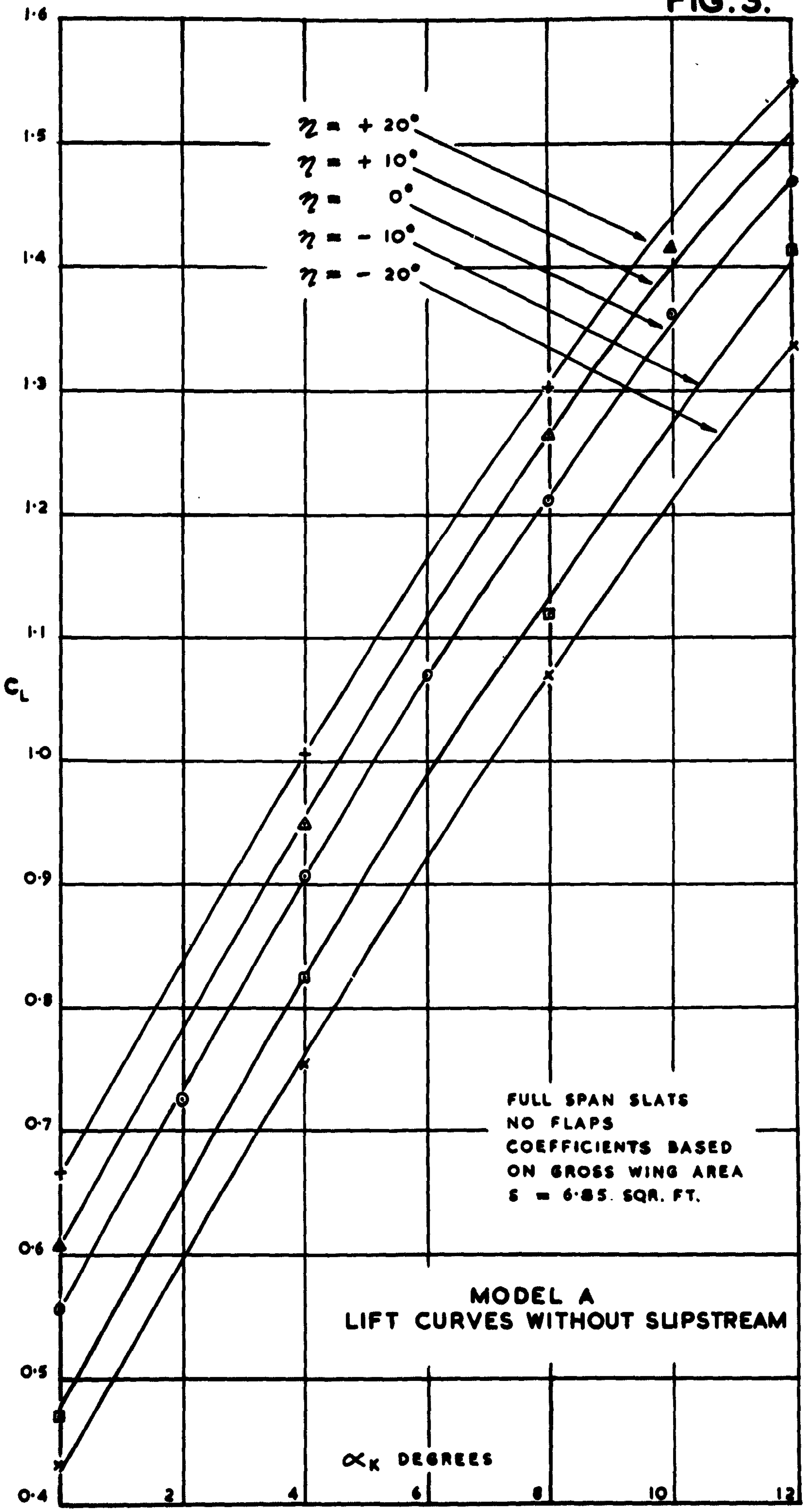
MODEL A

HULL LINES

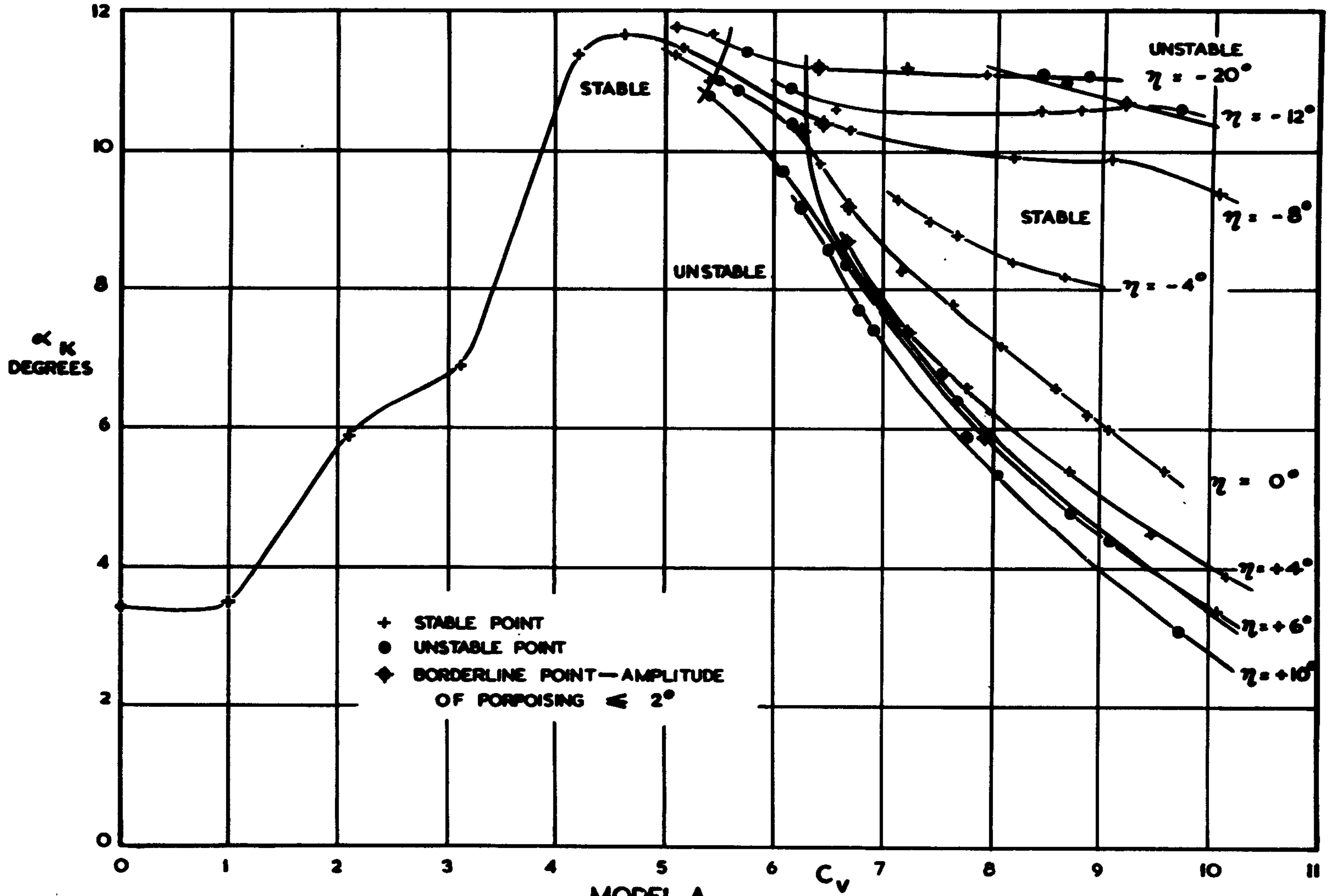
FIG. 2

PHOTOGRAPHS OF MODEL A

FIG. 3.



MODEL A
LIFT CURVES WITHOUT SLIPSTREAM

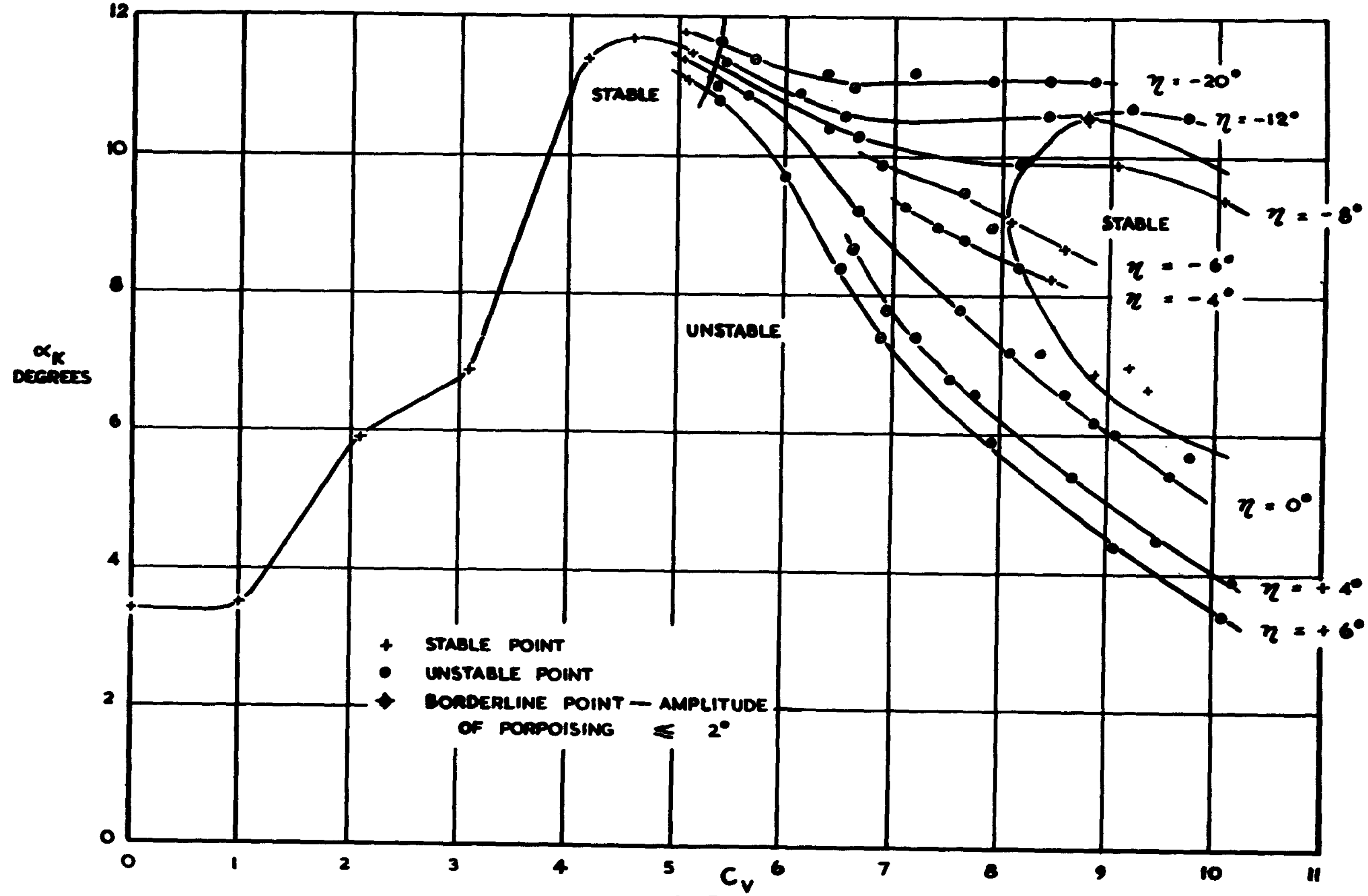


MODEL A

LONGITUDINAL STABILITY WITHOUT DISTURBANCE, $C_{\Delta_0} = 2{\cdot}75$.

FIG. 4.

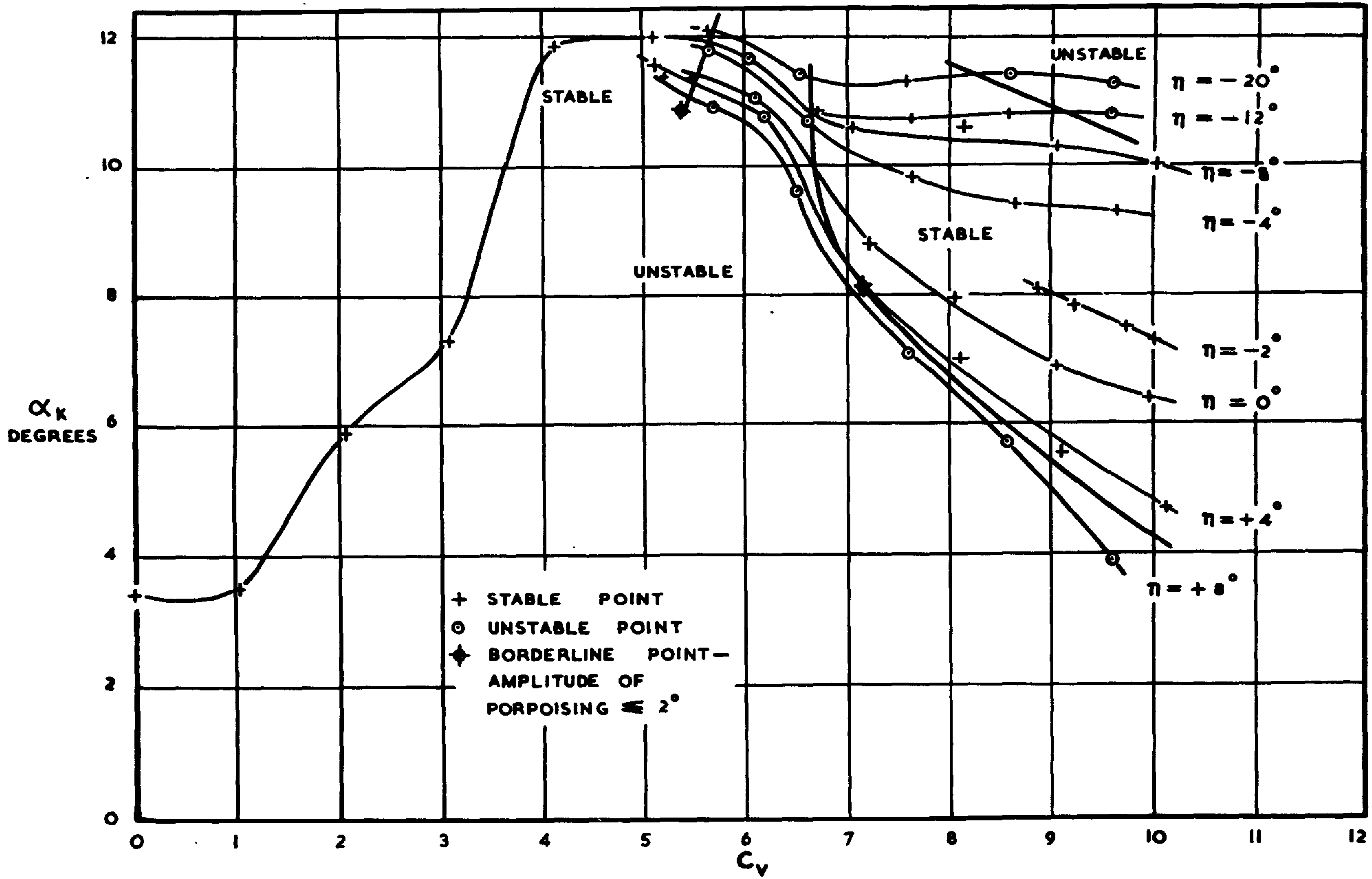
FIG. 5.



MODEL A

LONGITUDINAL STABILITY WITH DISTURBANCE, $C_{\Delta_0} = 2{\cdot}75$.

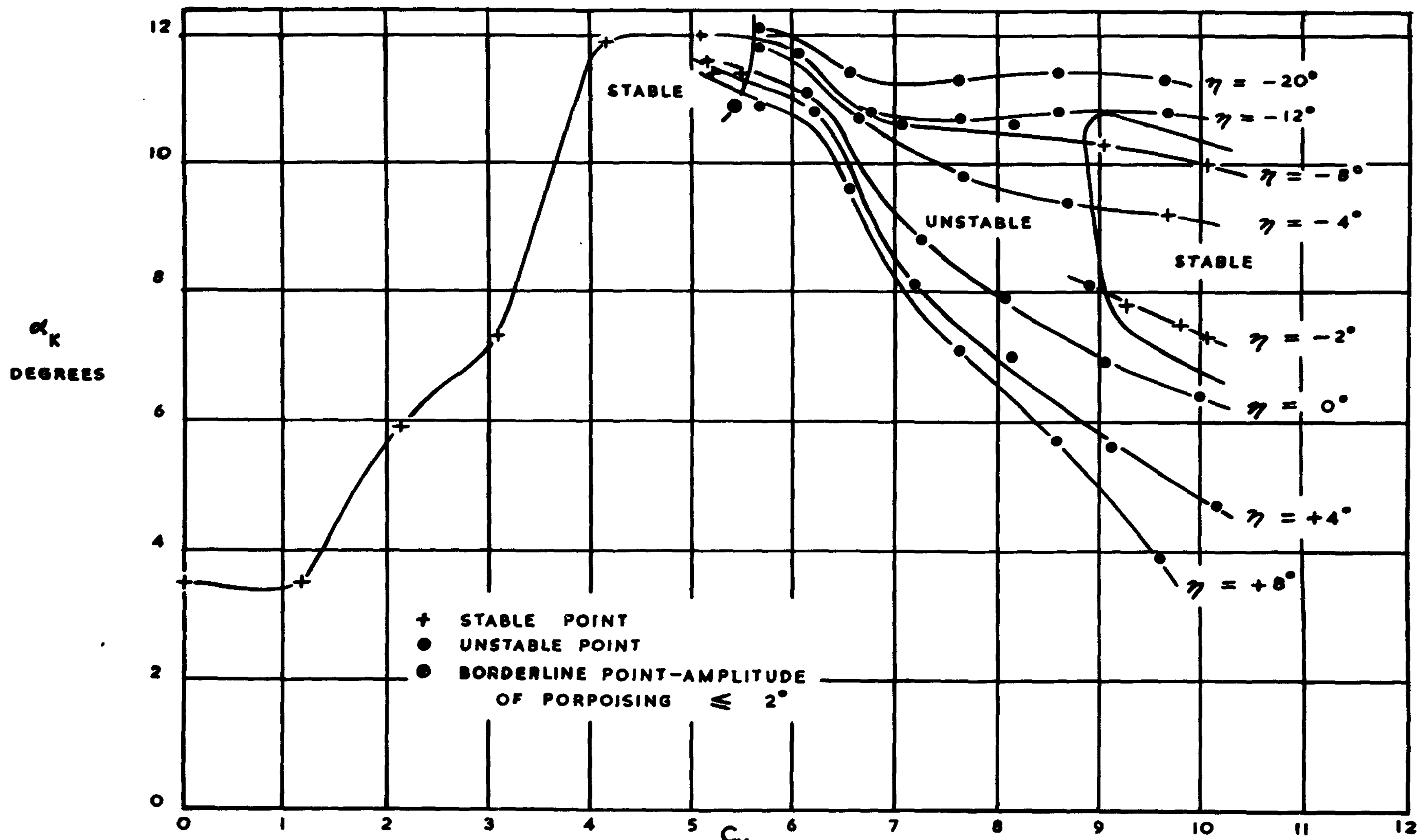
FIG.6.



MODEL A

LONGITUDINAL STABILITY WITHOUT DISTURBANCE, $C_{\Delta_0} = 3{\cdot}00$.

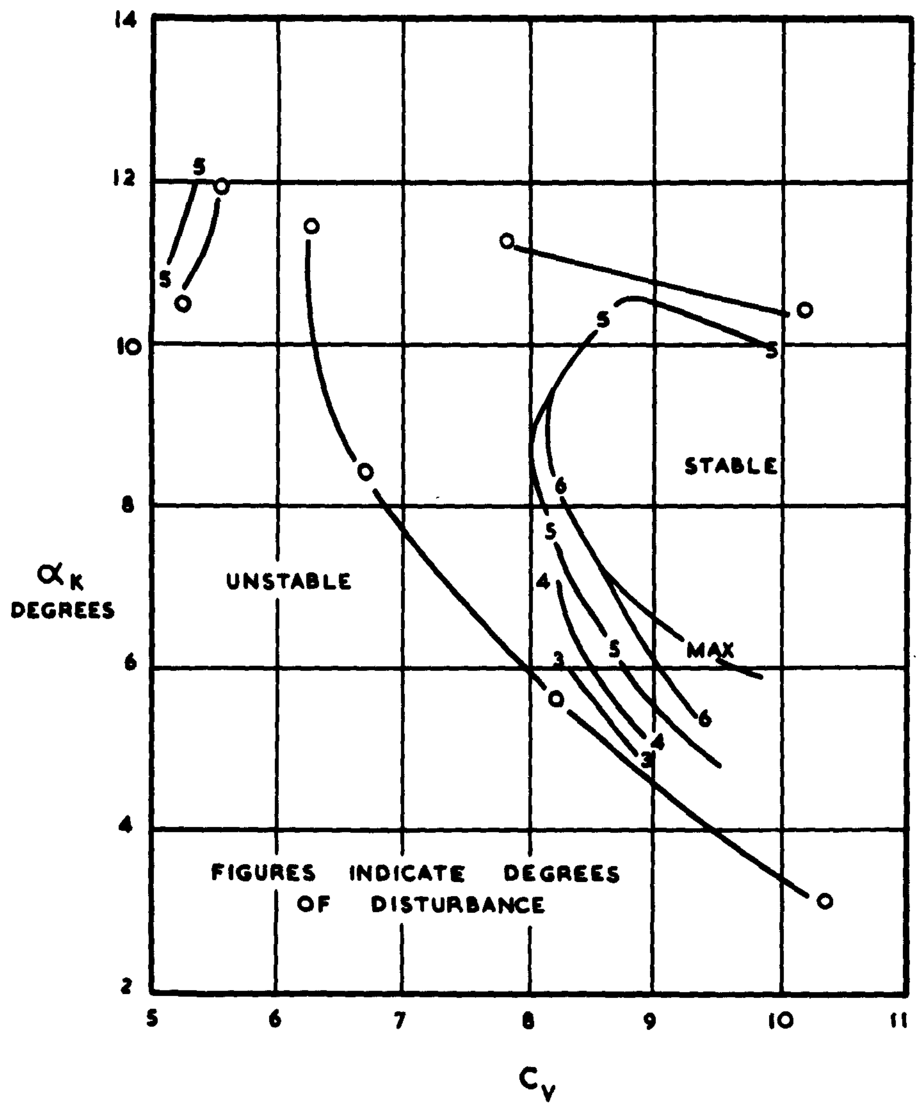
FIG. 7.



MODEL A

LONGITUDINAL STABILITY WITH DISTURBANCE, $C_{\Delta_0} = 3{\cdot}00$

FIG. 8.



MODEL A

LONGITUDINAL STABILITY LIMITS FOR 0,3,4,5,6 AND 7 DEGREES OF DISTURBANCE, $C_{\Delta_0} = 2{\cdot}75$.

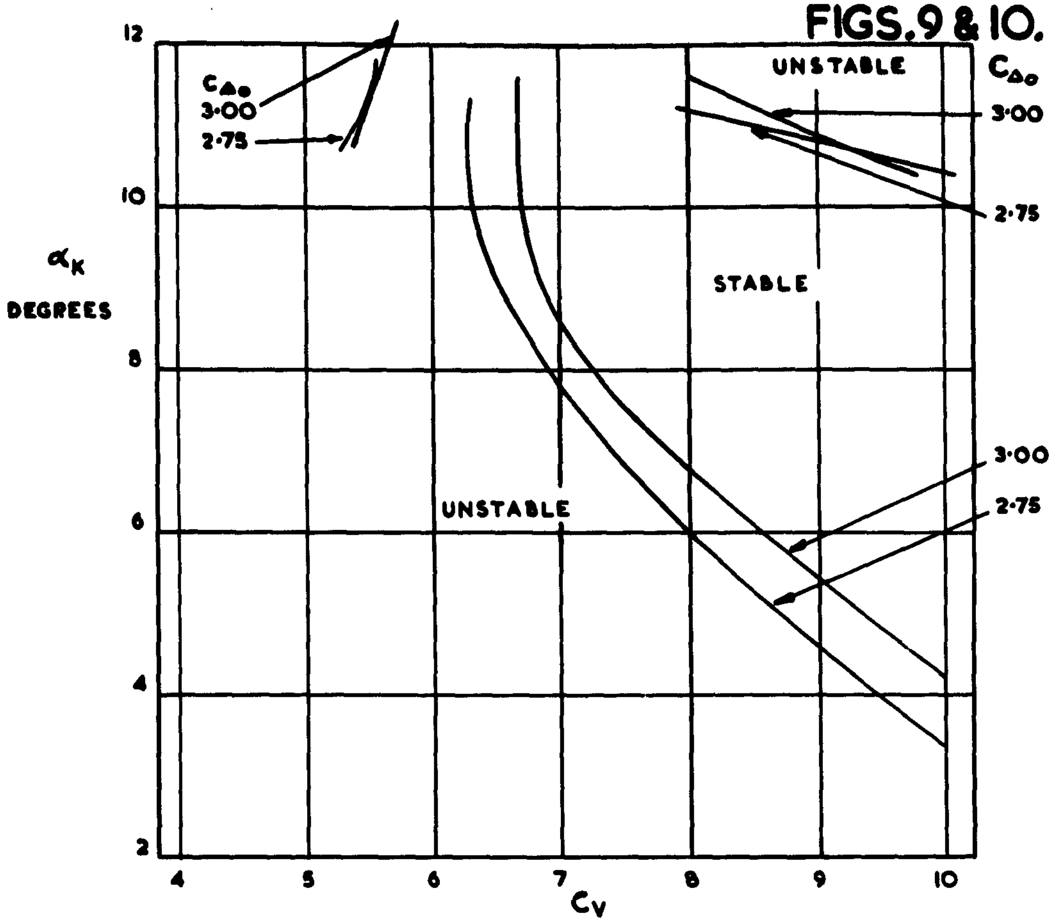


FIG. 9 MODEL A. COMPARISON OF UNDISTURBED LONGITUDINAL STABILITY LIMITS ON A C_V BASE

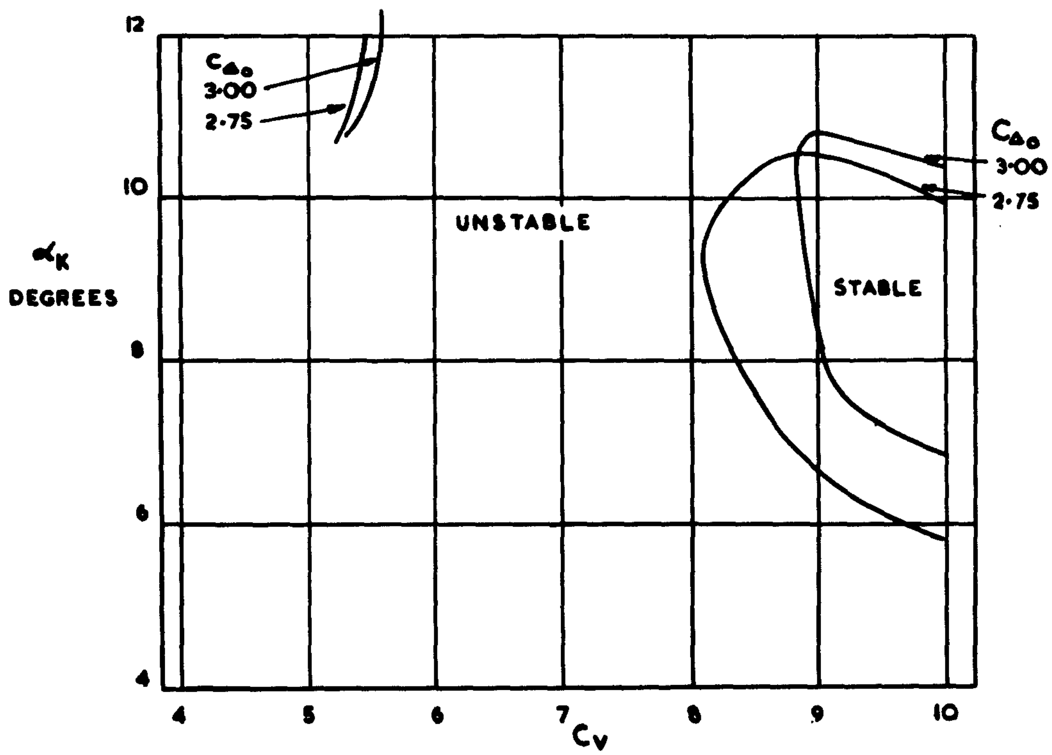
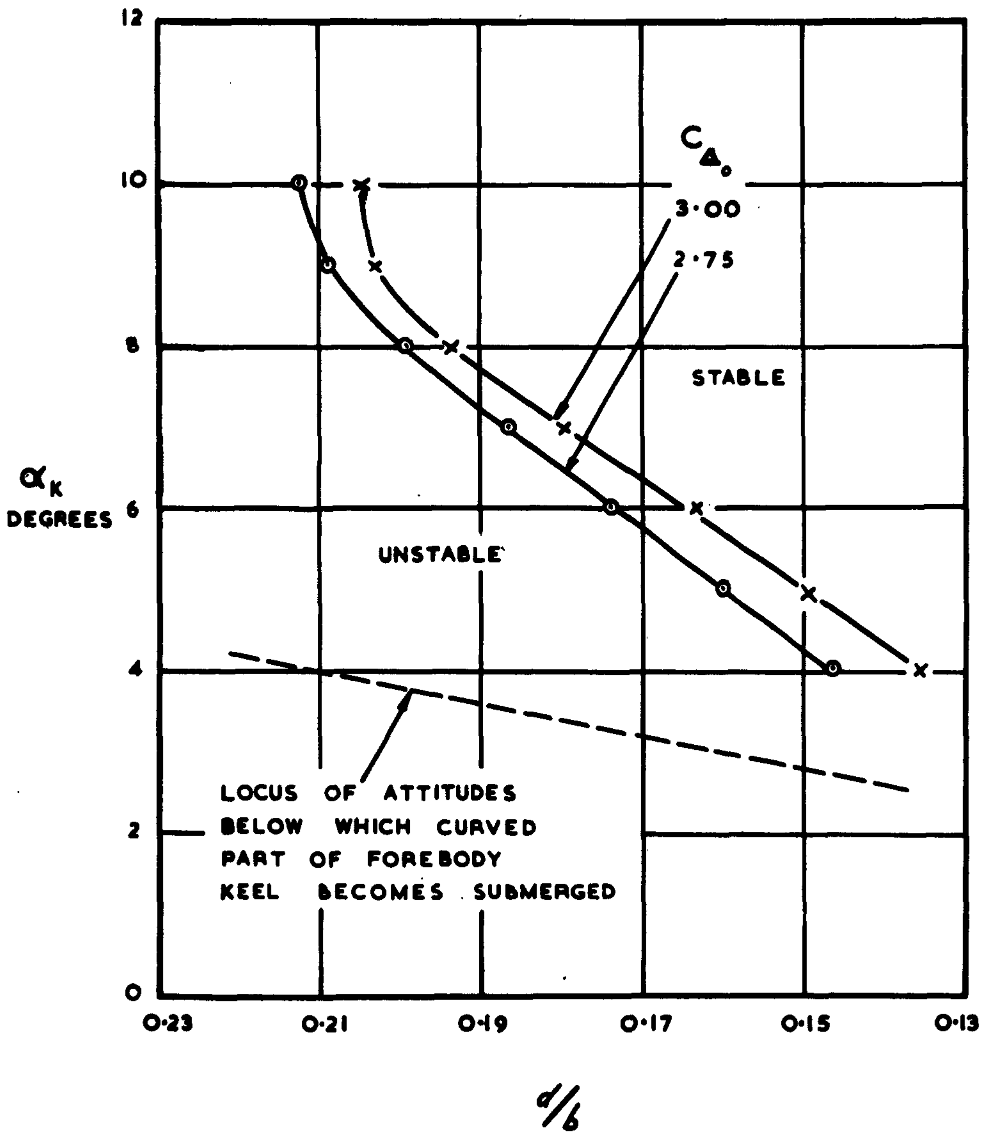


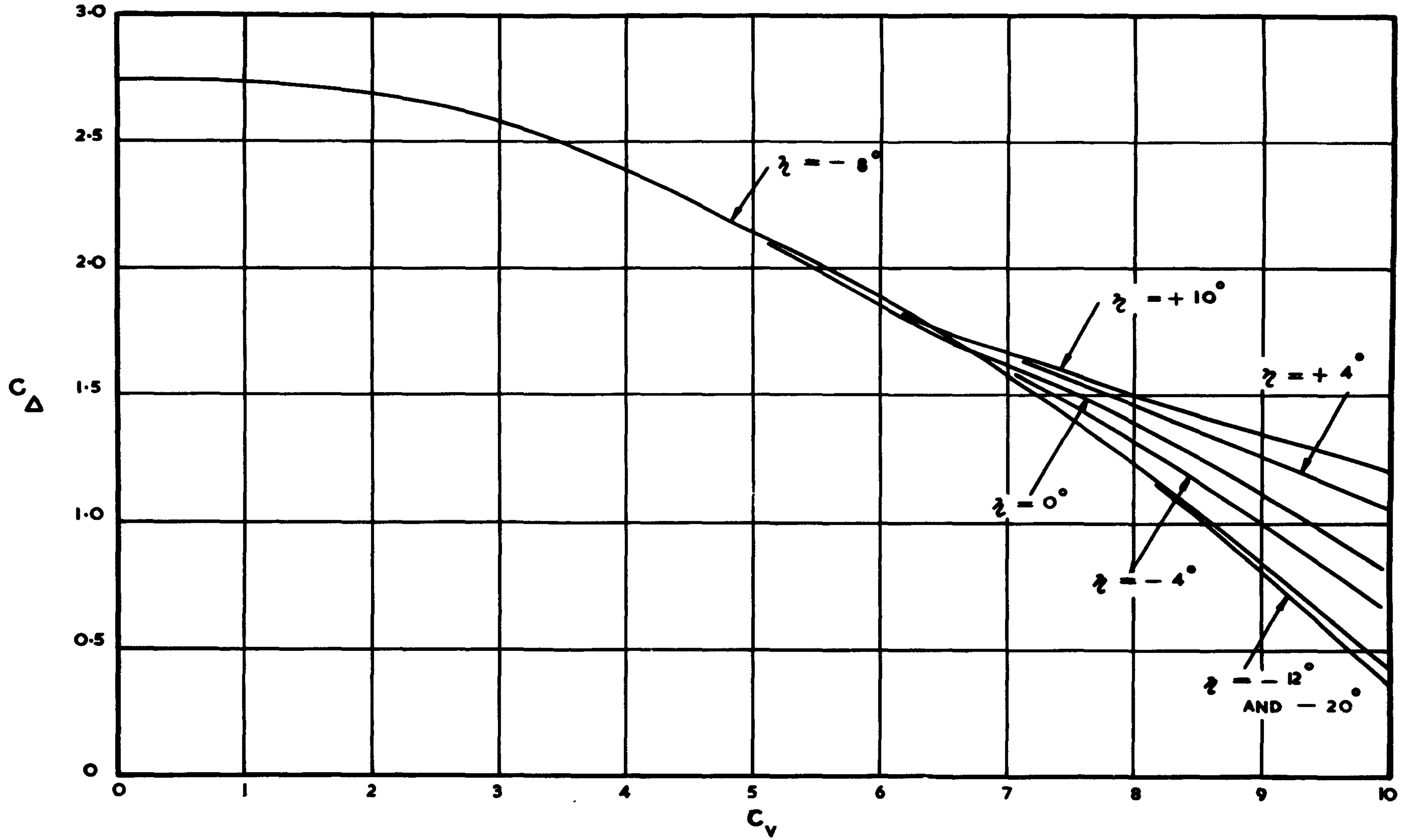
FIG. 10 MODEL A. COMPARISON OF DISTURBED LONGITUDINAL STABILITY LIMITS ON A C_V BASE



MODEL A

COMPARISON OF LOWER UNDISTURBED LONGITUDINAL STABILITY LIMITS ON A DRAUGHT BASE

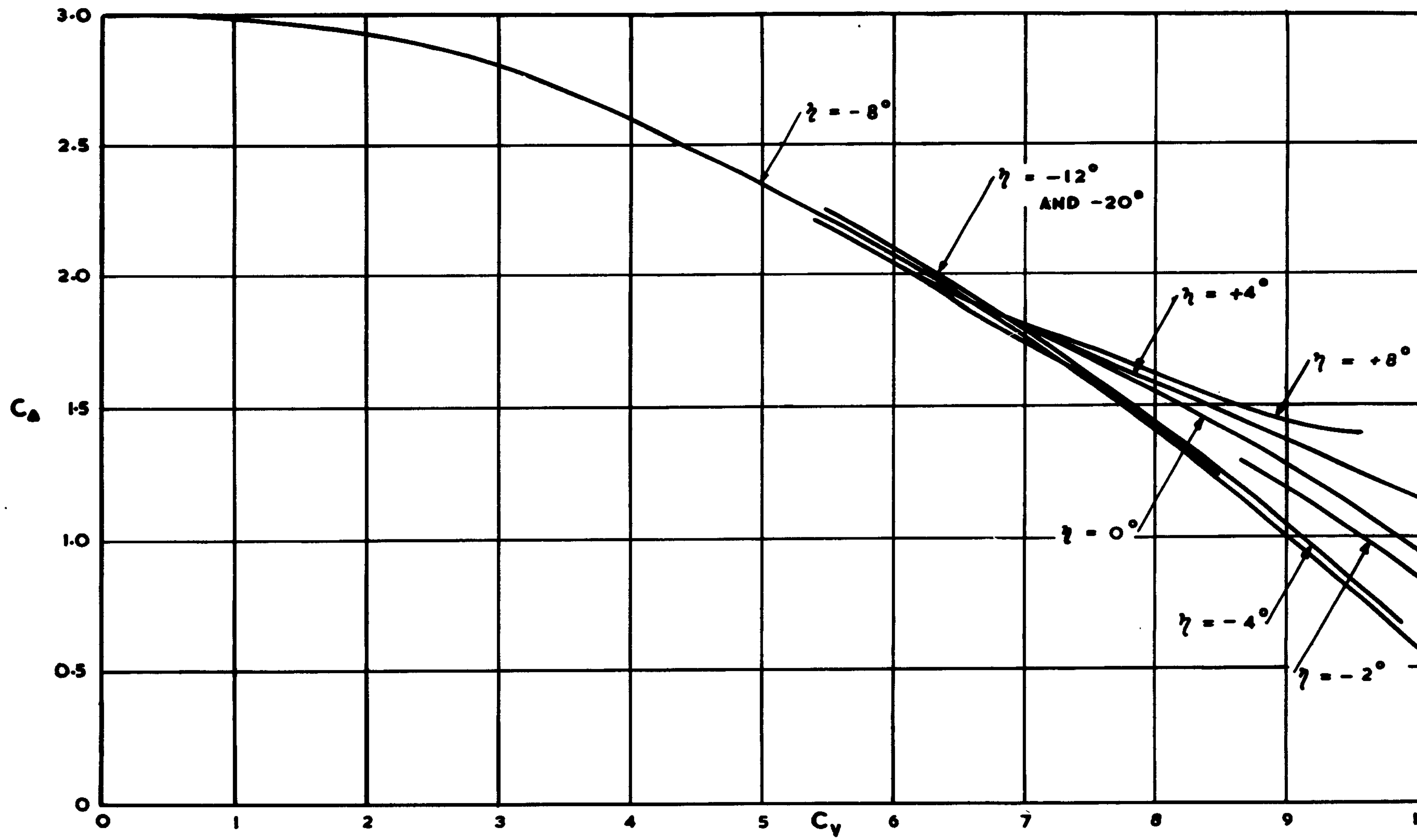
FIG.12.



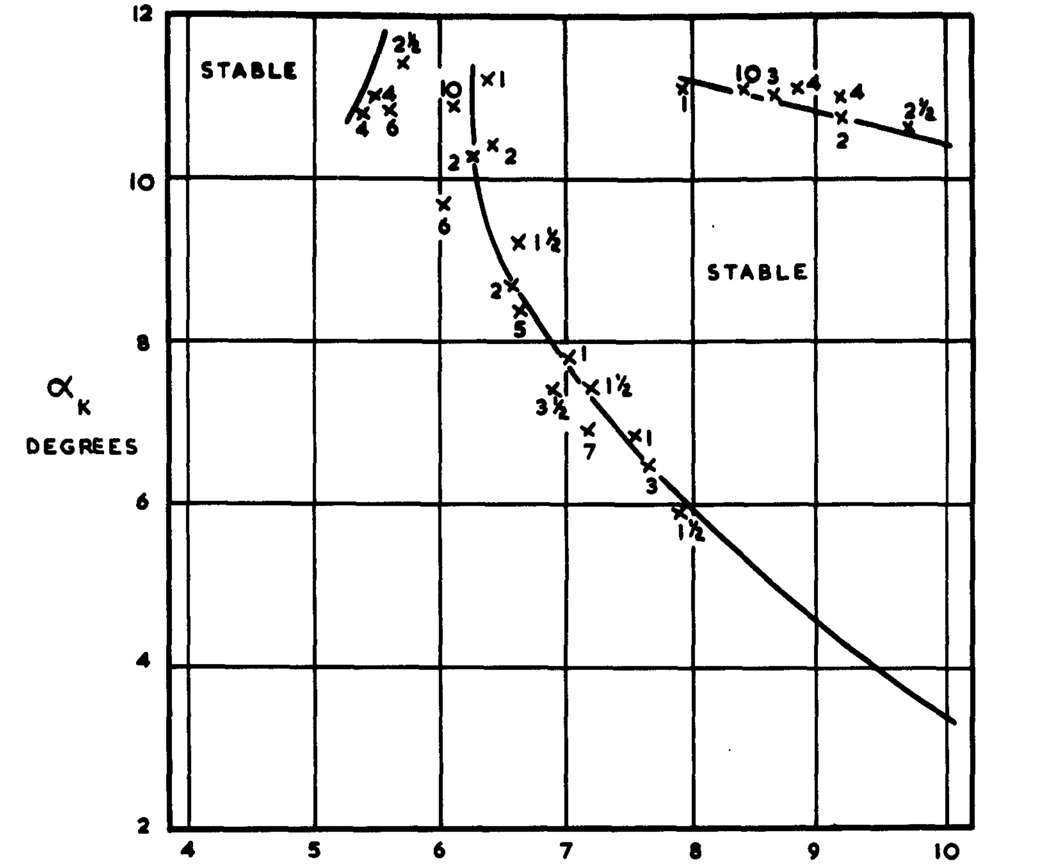
MODEL A

LOAD COEFFICIENT CURVES, $C_{\Delta_0} = 2{\cdot}75$.

FIG. 13.

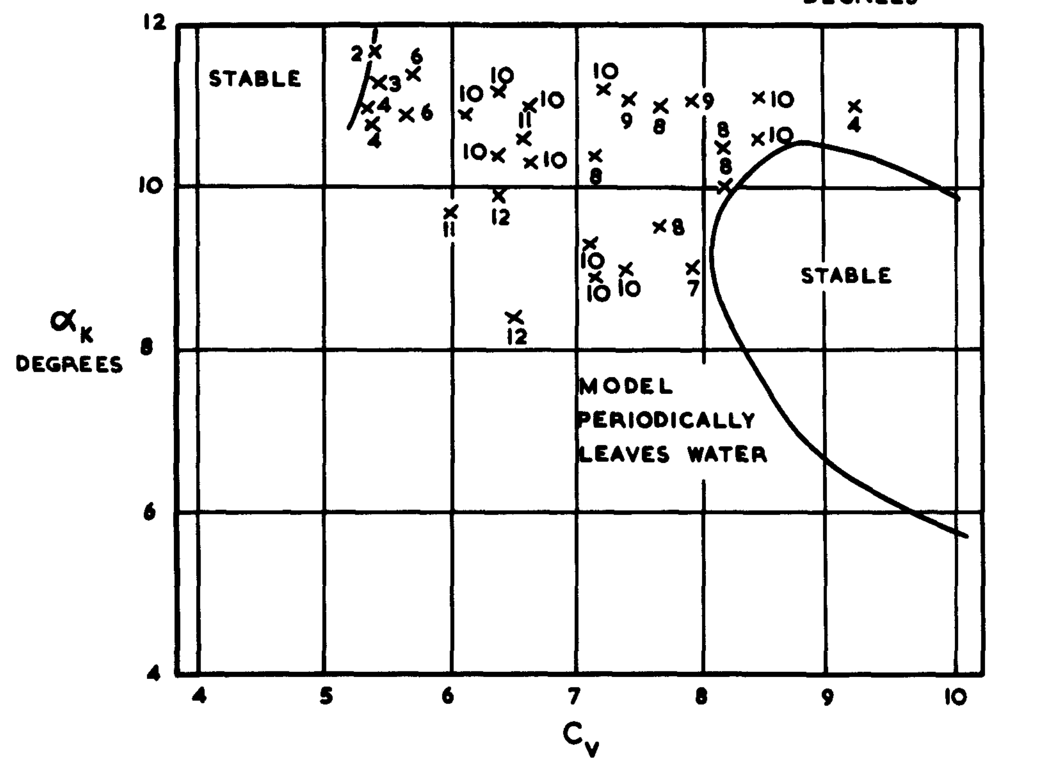


MODEL A
LOAD COEFFICIENT CURVES, $C_{\Delta_0} = 3.00$.



FIGURES INDICATE AMPLITUDES OF PORPOISING IN DEGREES

UNDISTURBED CASE

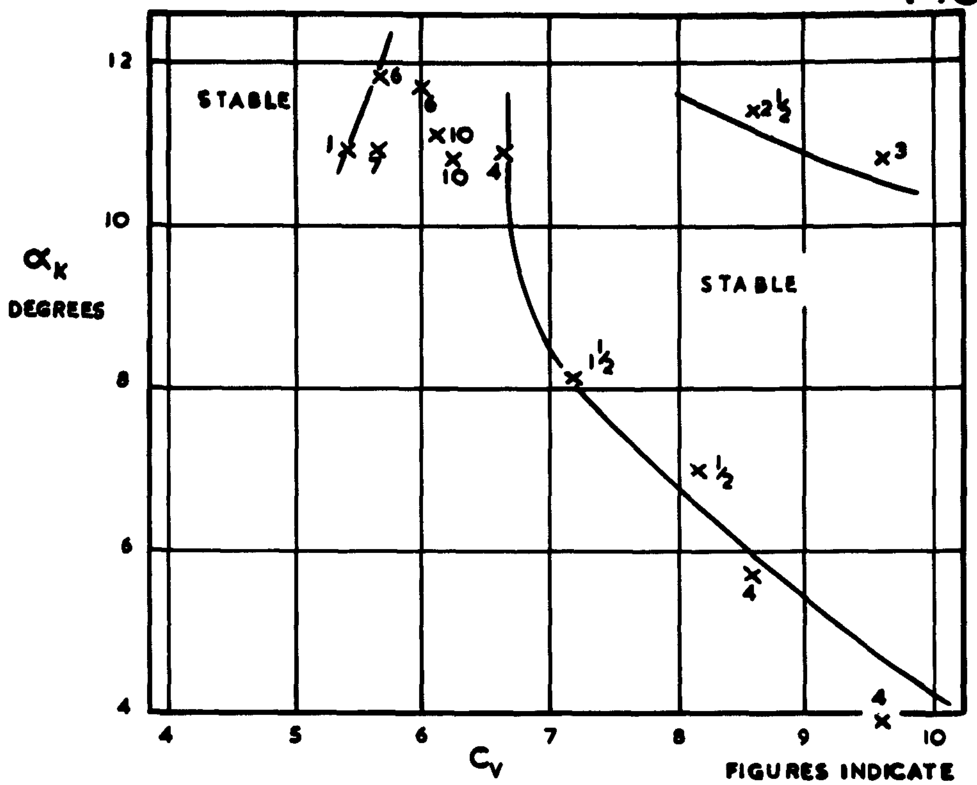


DISTURBED CASE

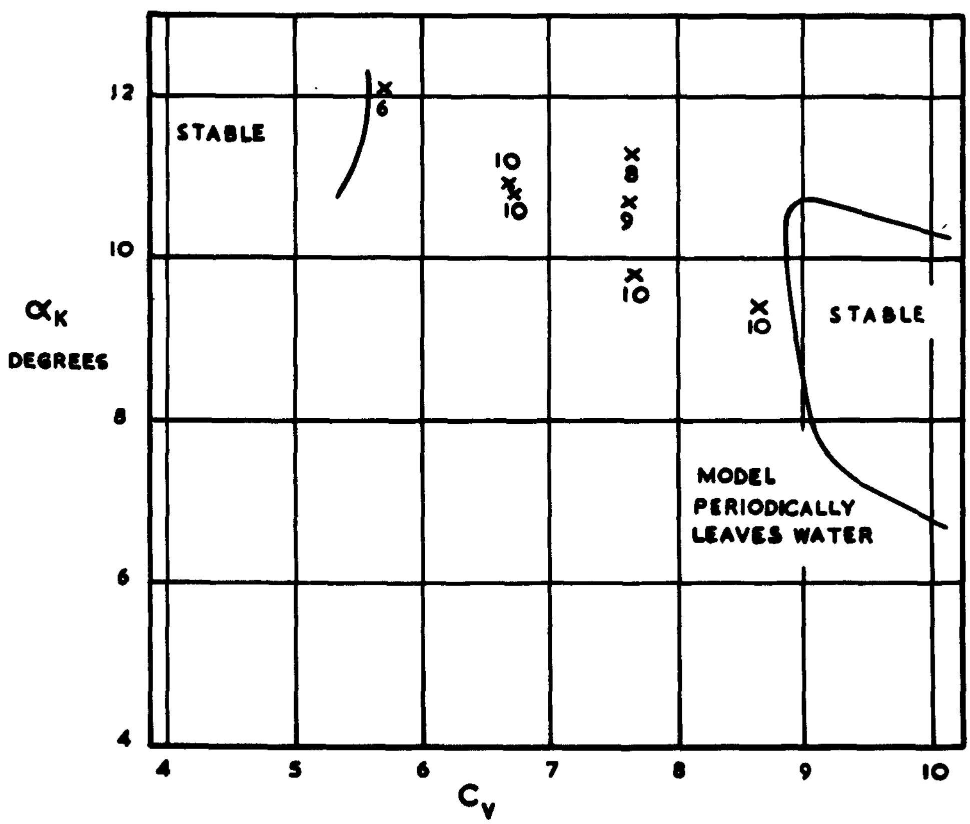
MODEL A

PORPOISING AMPLITUDES AND STABILITY LIMITS, $C_{\Delta_0}=2{\cdot}75$.

FIG.15.



UNDISTURBED CASE

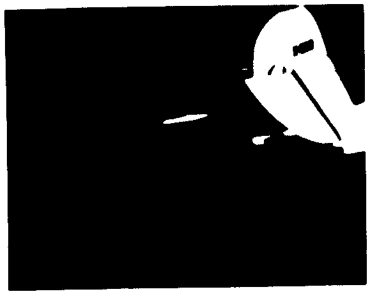


DISTURBED CASE

MODEL A

PORPOISING AMPLITUDES AND STABILITY LIMITS, $C_{\Delta_0} = 3{\cdot}00$.

FIG 16

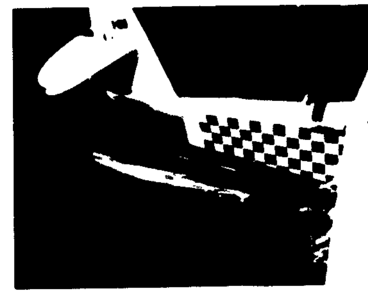


(a)

$\eta = -16^\circ$

$C_V = 6{\cdot}86$

$\alpha_k = 10{\cdot}8^\circ$

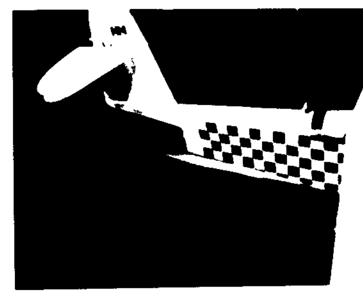


(b)

$\eta = -8^\circ$

$C_V = 9{\cdot}35$

$\alpha_k = 9{\cdot}8^\circ$

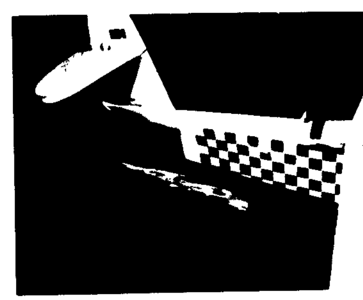


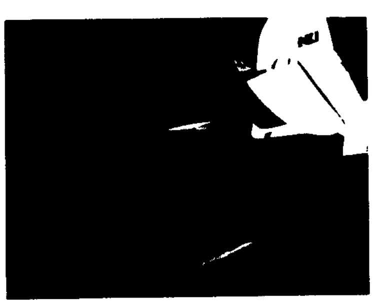
(c)

$\eta = -4^\circ$

$C_V = 8{\cdot}17$

$\alpha_k = 8{\cdot}4^\circ$



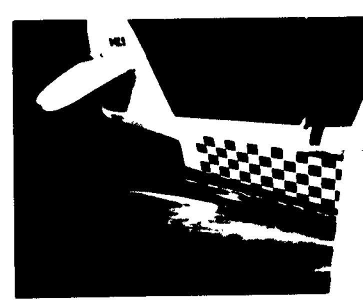


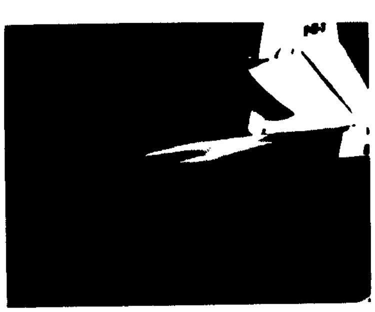
(d)

$\eta = +2^\circ$

$C_V = 6{\cdot}98$

$\alpha_k = 8{\cdot}4^\circ$



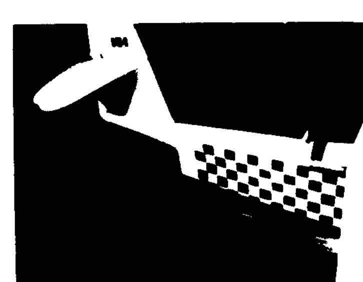


(e)

$\eta = +2^\circ$

$C_V = 9{\cdot}41$

$\alpha_k = 5{\cdot}0^\circ$



MODEL A

WAKE PHOTOGRAPHS

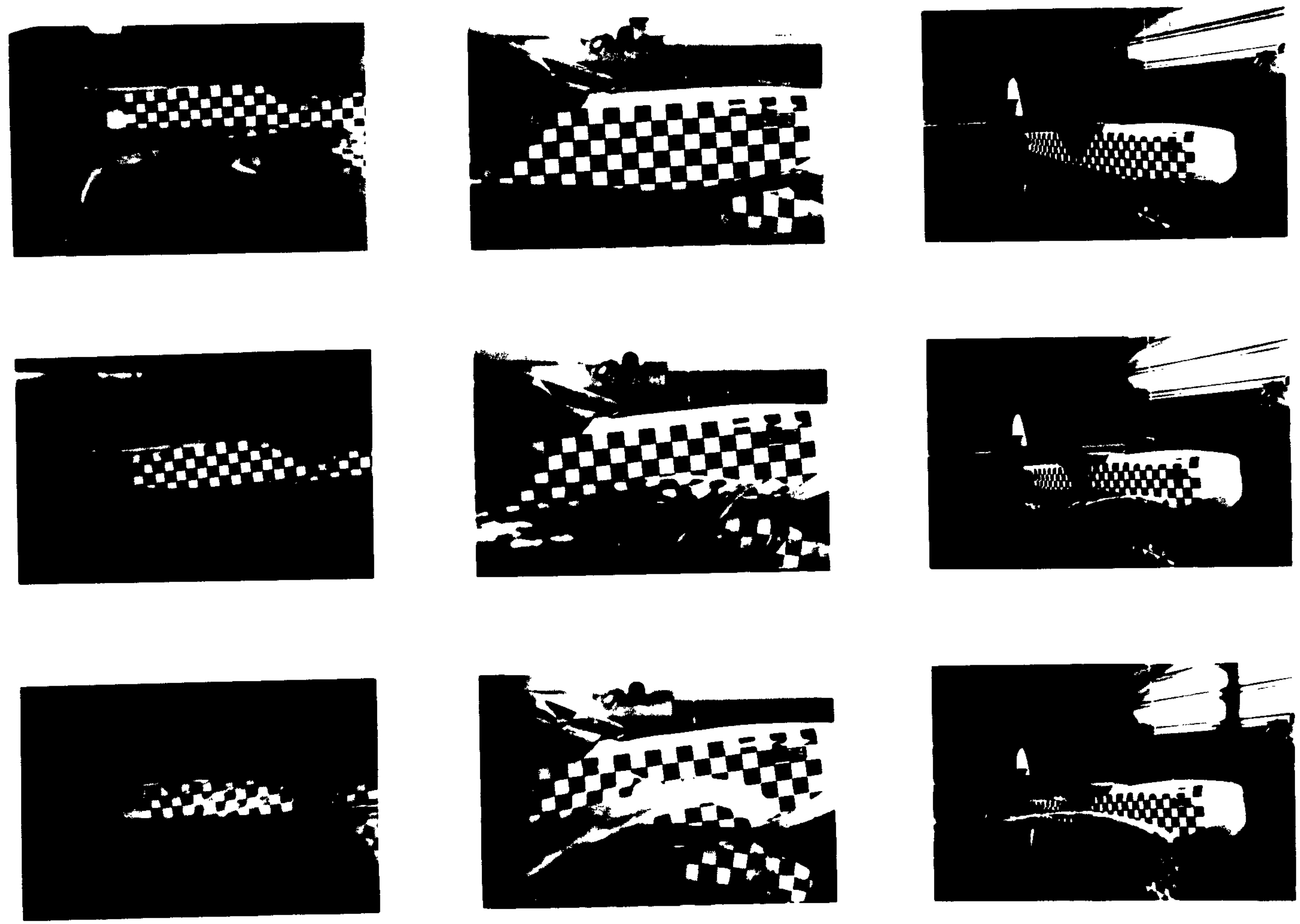
$C_{\Delta_0} = 2{\cdot}75$

FIG 17

(a)
$\eta = -8^\circ$
$C_v = 1{\cdot}02$
$\alpha_\cdot = 3{\cdot}5^\circ$

(b)
$\eta = -8^\circ$
$C_v = 2{\cdot}05$
$\alpha_\cdot = 5{\cdot}9^\circ$

(c)
$\eta = -8^\circ$
$C_v = 3{\cdot}07$
$\alpha_\cdot = 6{\cdot}9^\circ$



MODEL A

SPRAY PHOTOGRAPHS, $C_{\Delta_0} = 2{\cdot}75$, (1)

(a)

$\eta = -8^\circ$

$C_v = 4{\cdot}09$

$\alpha_v = 11{\cdot}1^\circ$

(b)

$\eta = -8^\circ$

$C_v = 5{\cdot}12$

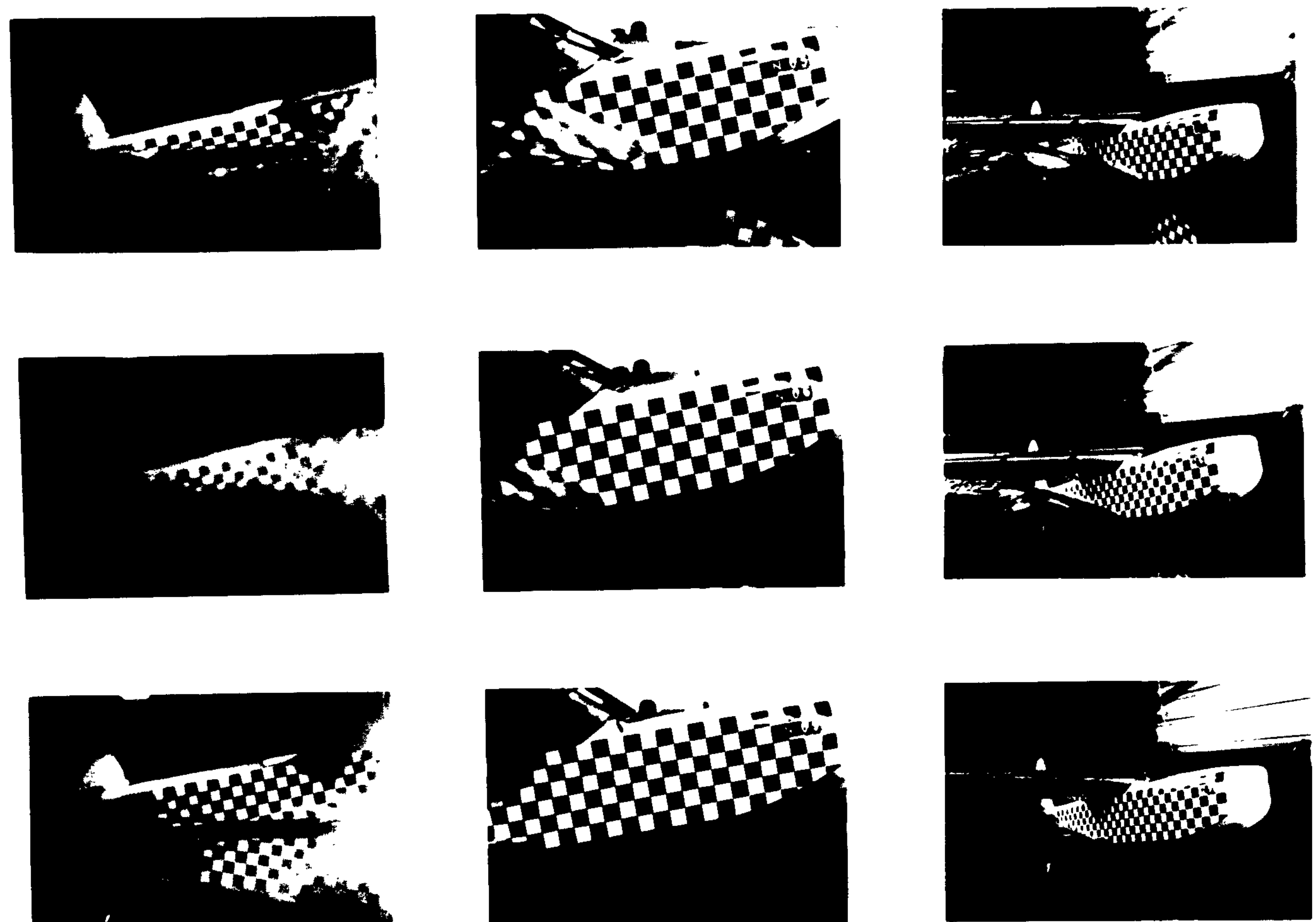
$\alpha_v = 11{\cdot}5^\circ$

(c)

$\eta = -8^\circ$

$C_v = 9{\cdot}21$

$\alpha_v = 9{\cdot}9^\circ$



MODEL A

SPRAY PHOTOGRAPHS, $C_{\Delta_0} = 2{\cdot}75$, (2)

FIG 19

(a)

$\eta = -8^\circ$

$C_v = 1{\cdot}02$

$\alpha_k = 3{\cdot}5^\circ$

(b)

$\eta = -8^\circ$

$C_v = 2{\cdot}04$

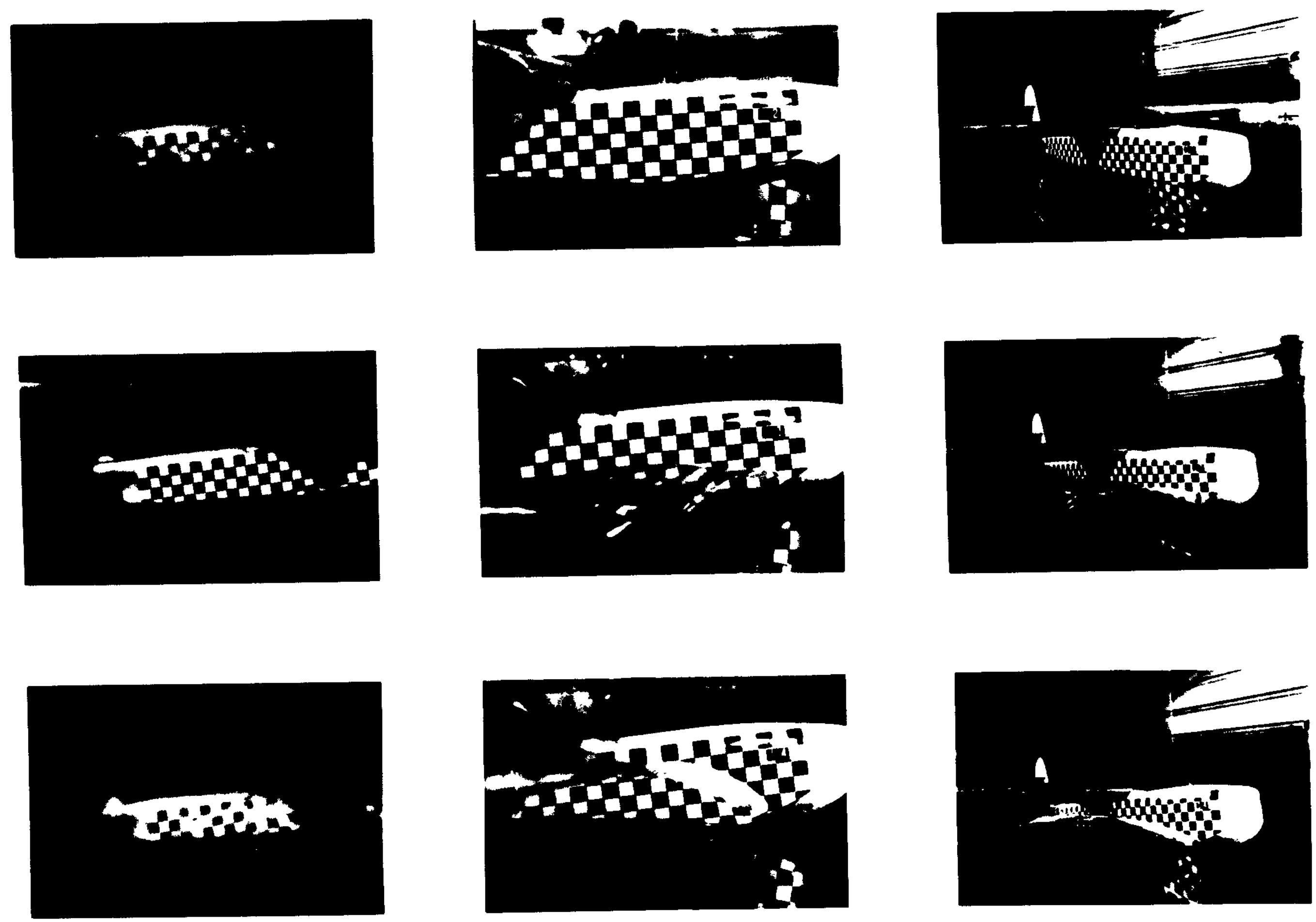
$\alpha_k = 5{\cdot}9^\circ$

(c)

$\eta = -8^\circ$

$C_v = 3{\cdot}07$

$\alpha_k = 7{\cdot}3^\circ$



MODEL A

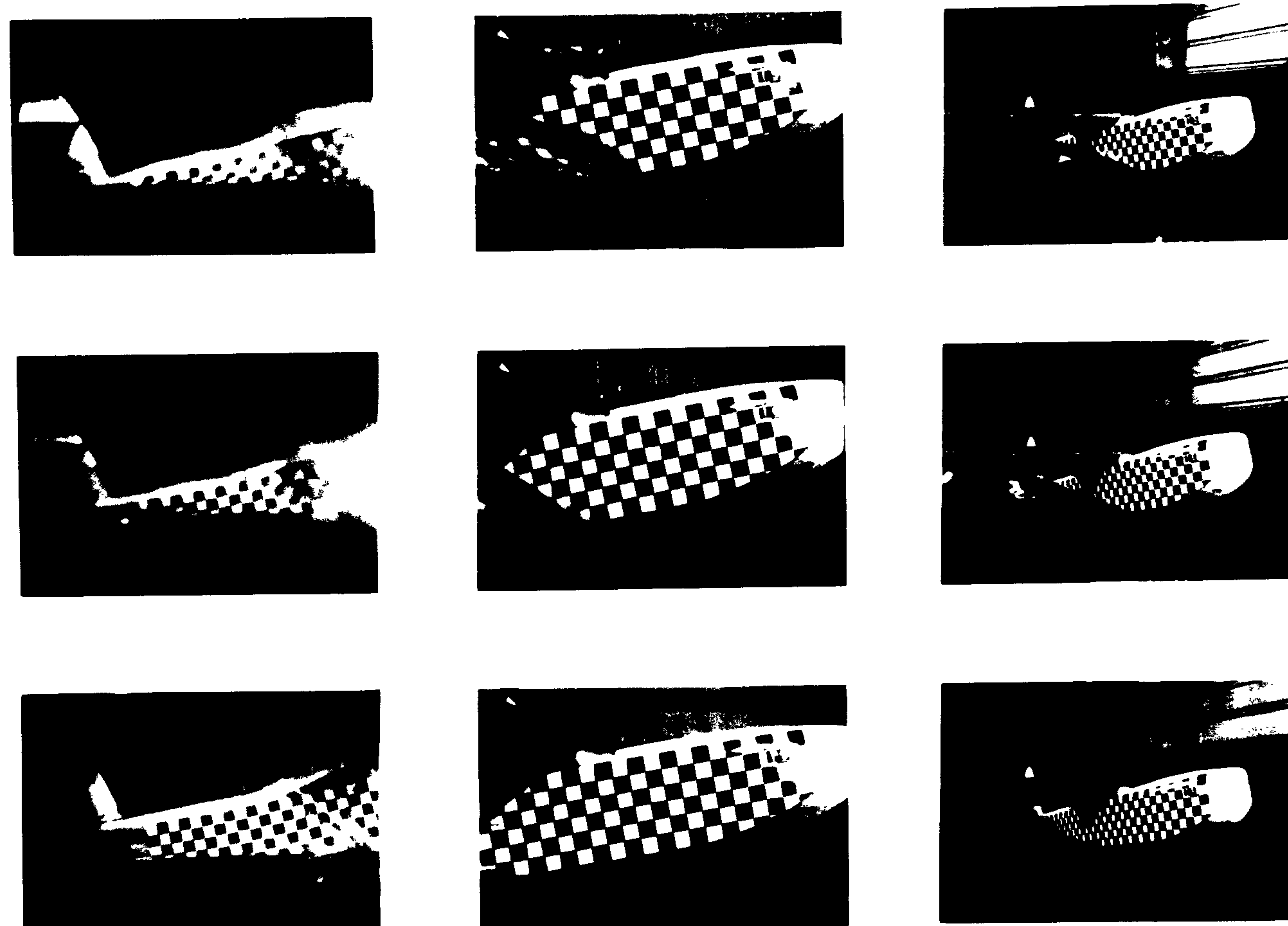
SPRAY PHOTOGRAPHS, $C_{\Delta_0} = 3{\cdot}00$, (I)

FIG 20.

(a) $\eta = -8^\circ$, $C_v = 4{\cdot}12$, $\alpha_K = 11{\cdot}9^\circ$

(b) $\eta = -8^\circ$, $C_v = 5{\cdot}06$, $\alpha_K = 12{\cdot}0^\circ$

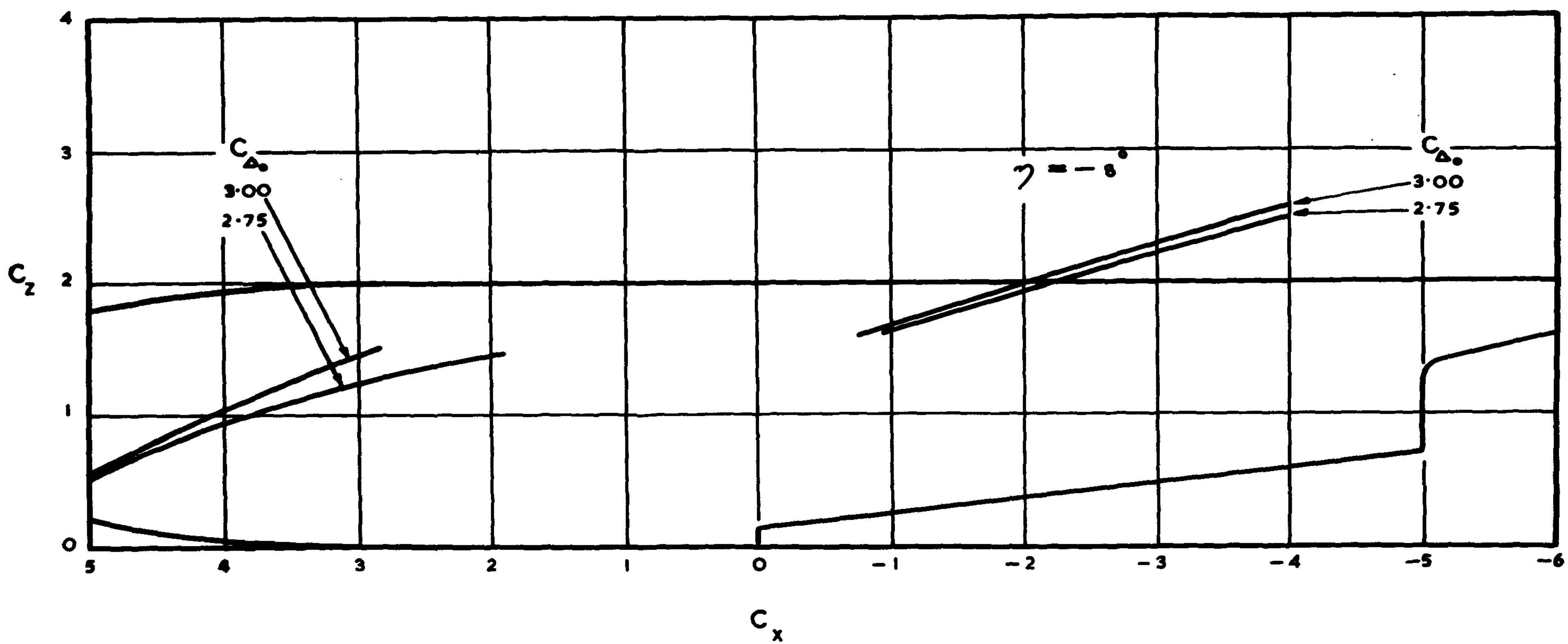
(c) $\eta = -8^\circ$, $C_v = 9{\cdot}05$, $\alpha_K = 10{\cdot}3^\circ$



MODEL A

SPRAY PHOTOGRAPHS, $C_{\Delta_0} = 3{\cdot}00$, (2)

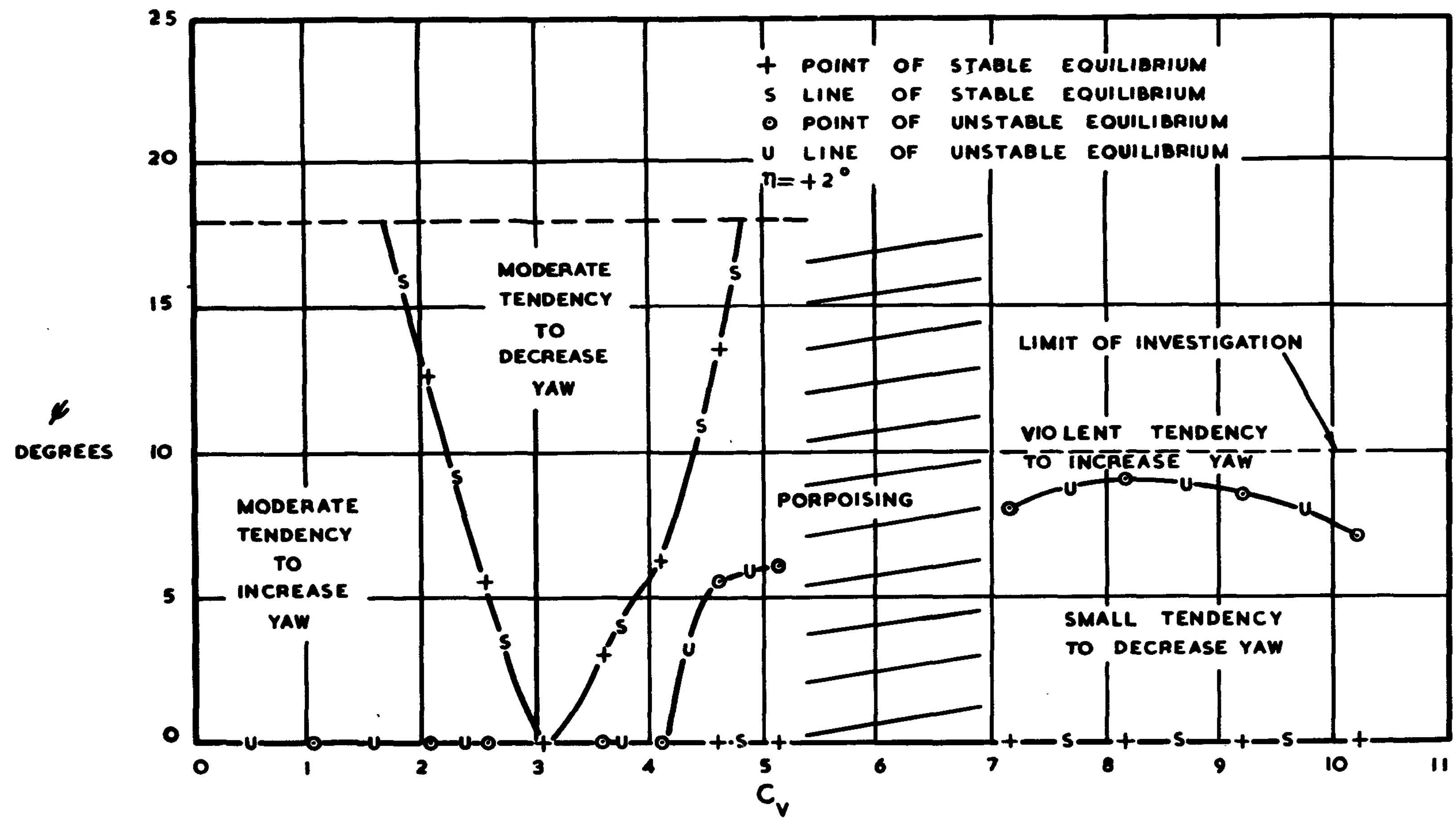
FIG. 21.



MODEL A

PROJECTIONS OF SPRAY ENVELOPES ON PLANE OF SYMMETRY OF MODEL

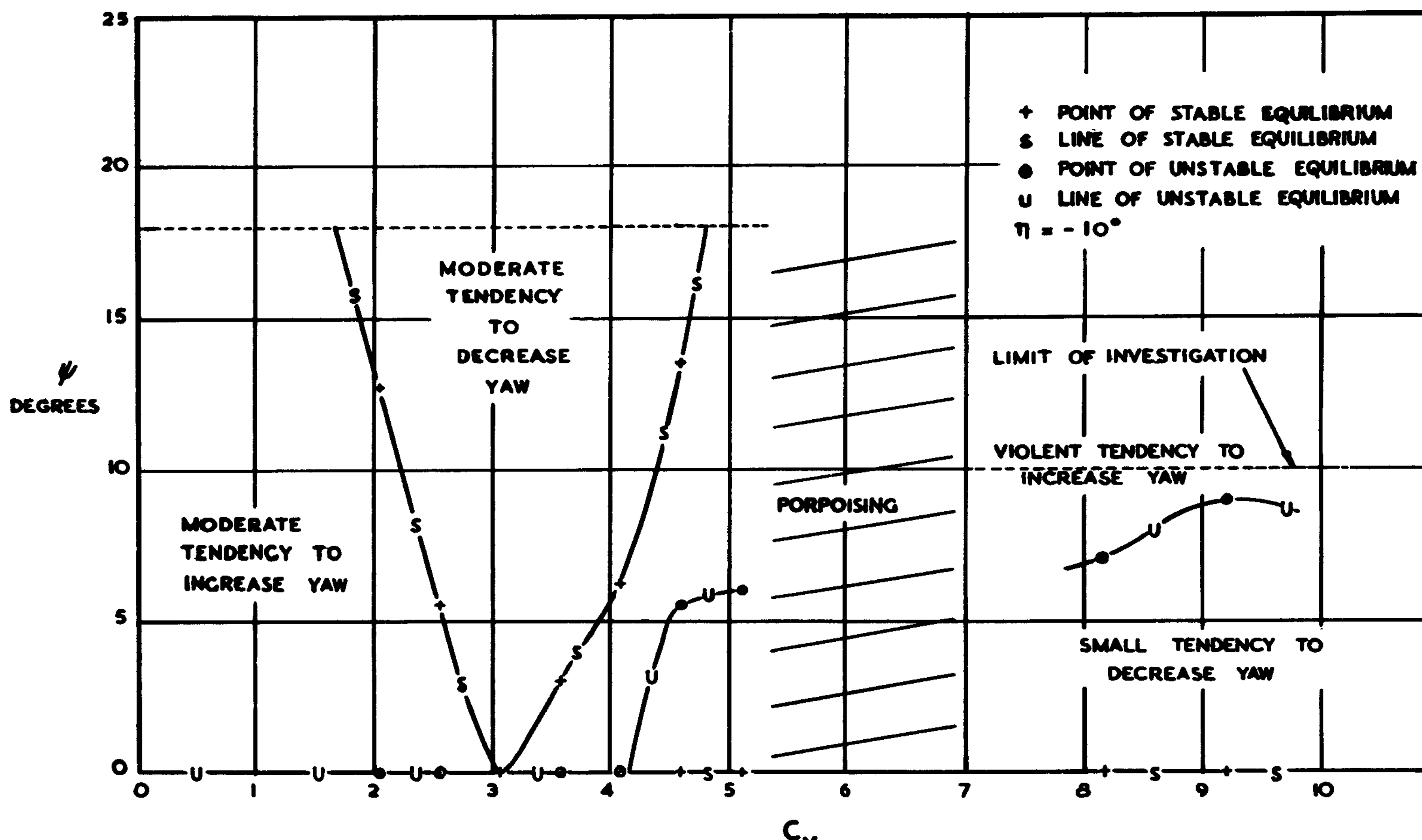
FIG. 22.



MODEL A

DIRECTIONAL STABILITY, $C_{\Delta_0} = 2{\cdot}75$, NO CONSTRAINT, LOW ATTITUDES.

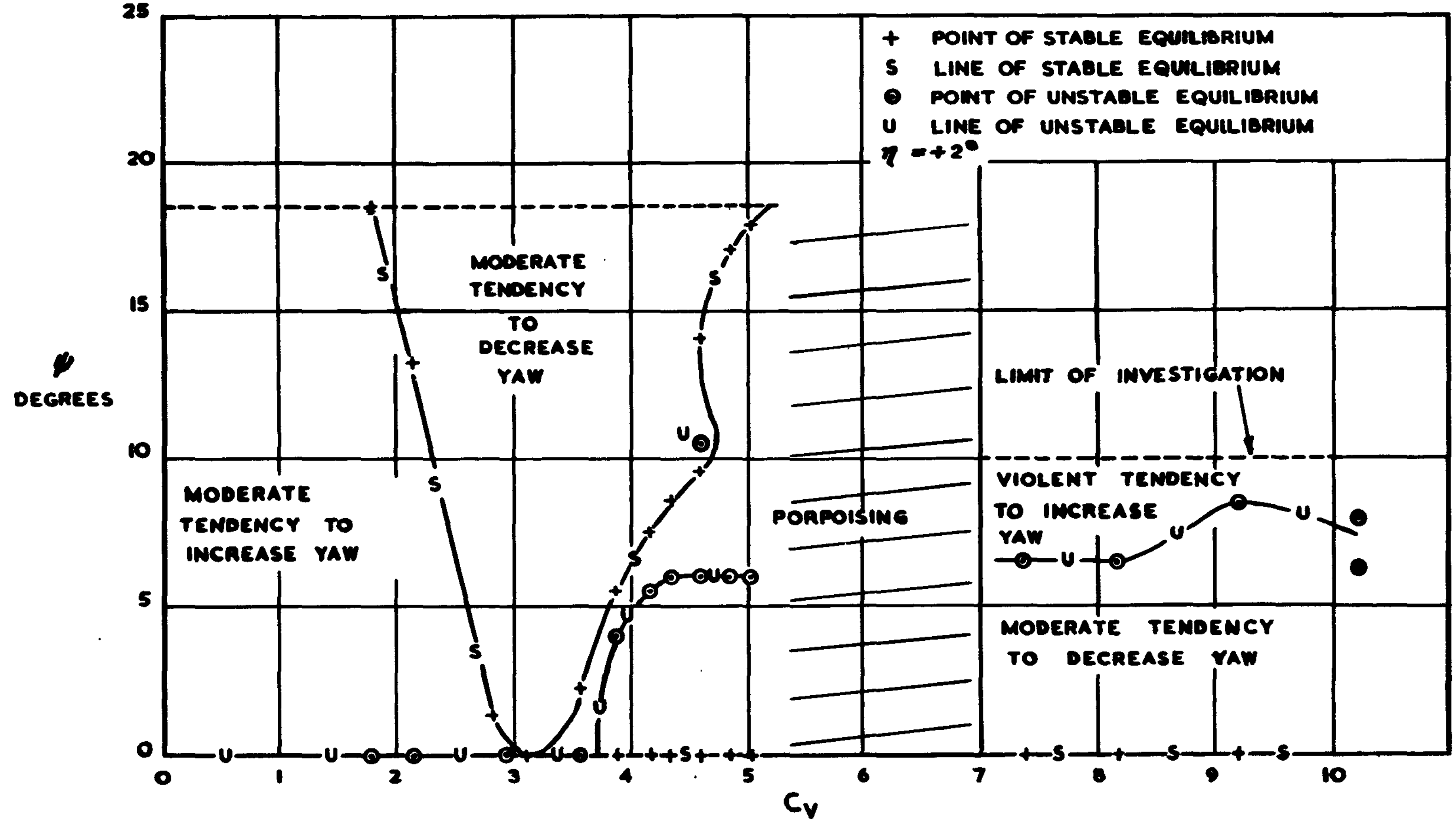
FIG. 23.



MODEL A

DIRECTIONAL STABILITY, C_{Δ_0} = 2·75, NO CONSTRAINT, HIGH ATTITUDES.

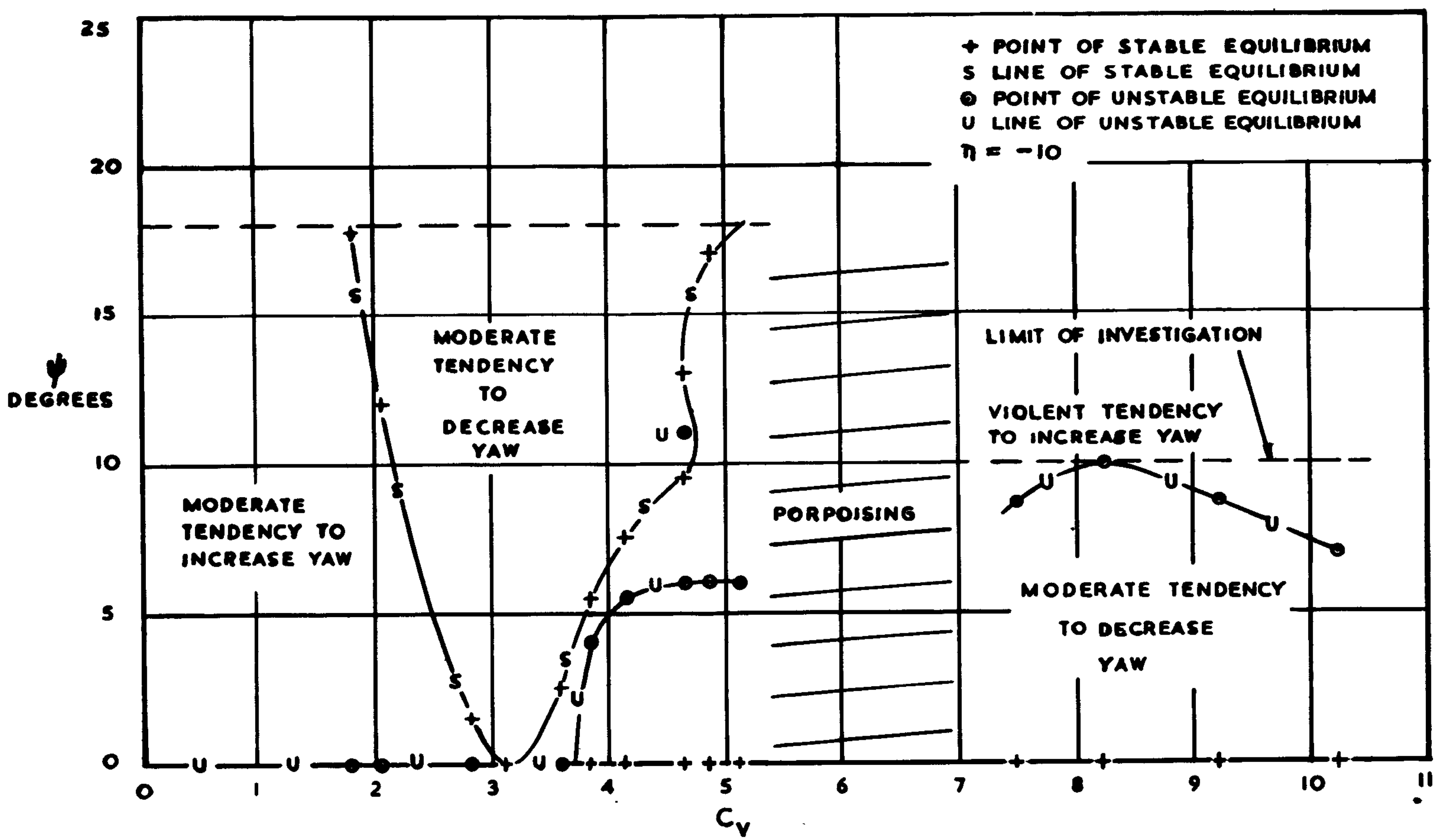
FIG. 24



MODEL A

DIRECTIONAL STABILITY, $C_{\Delta_0} = 2{\cdot}75$, CONSTRAINED IN ROLL, LOW ATTITUDES.

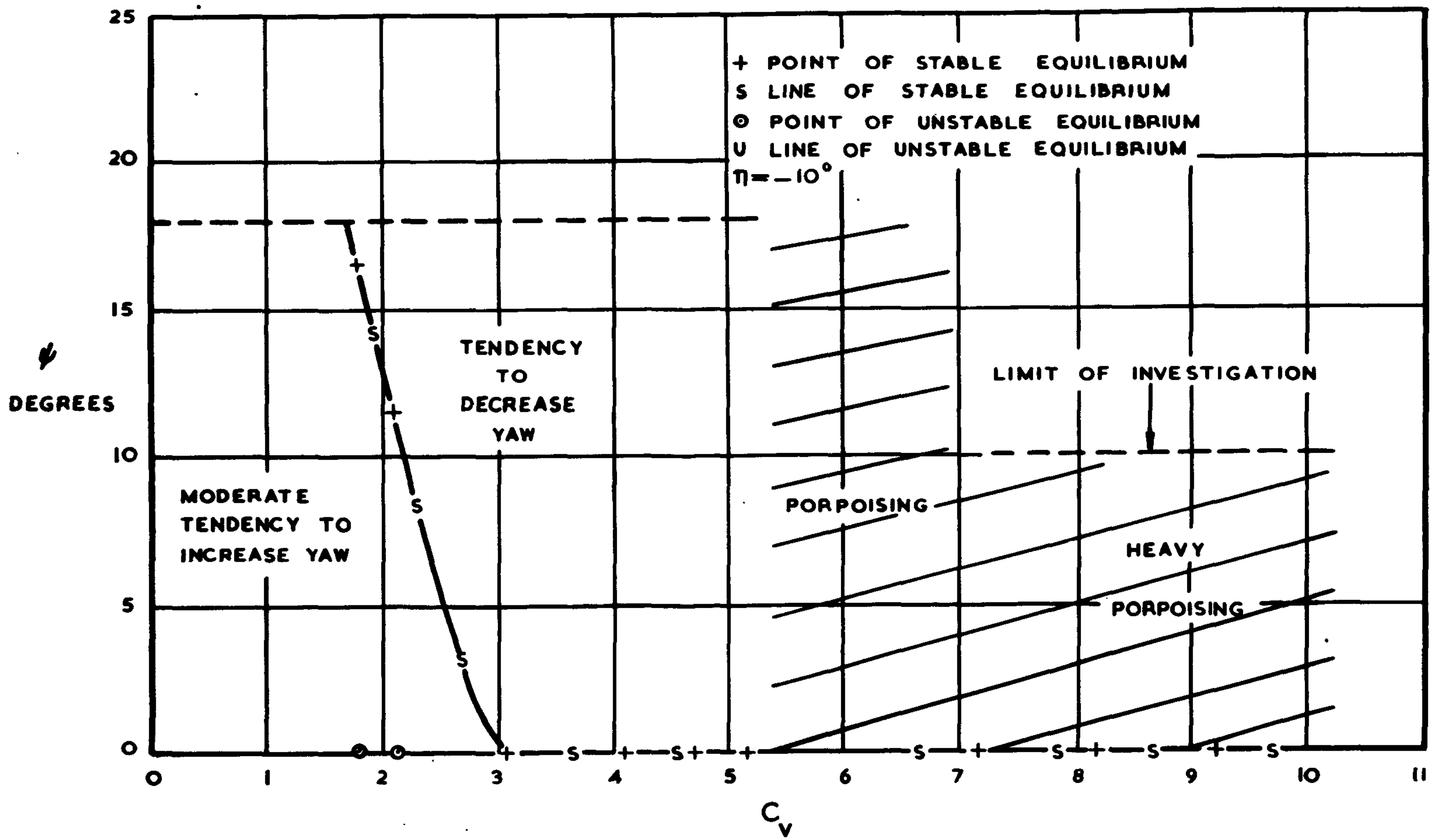
FIG. 25.



MODEL A

DIRECTIONAL STABILITY, $C_{\Delta_0} = 2{\cdot}75$, CONSTRAINED IN ROLL, HIGH ATTITUDES.

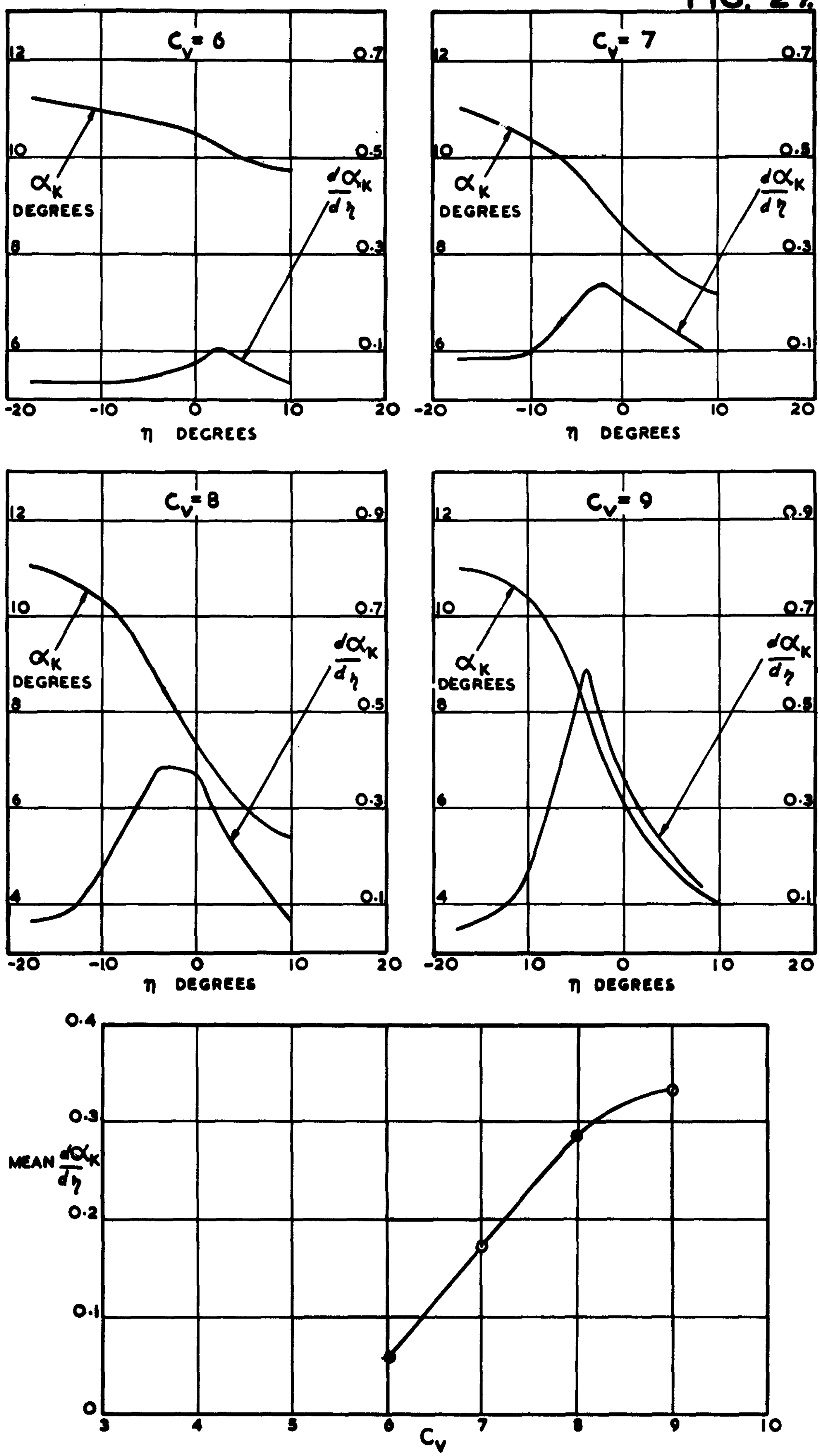
FIG. 26.



MODEL A

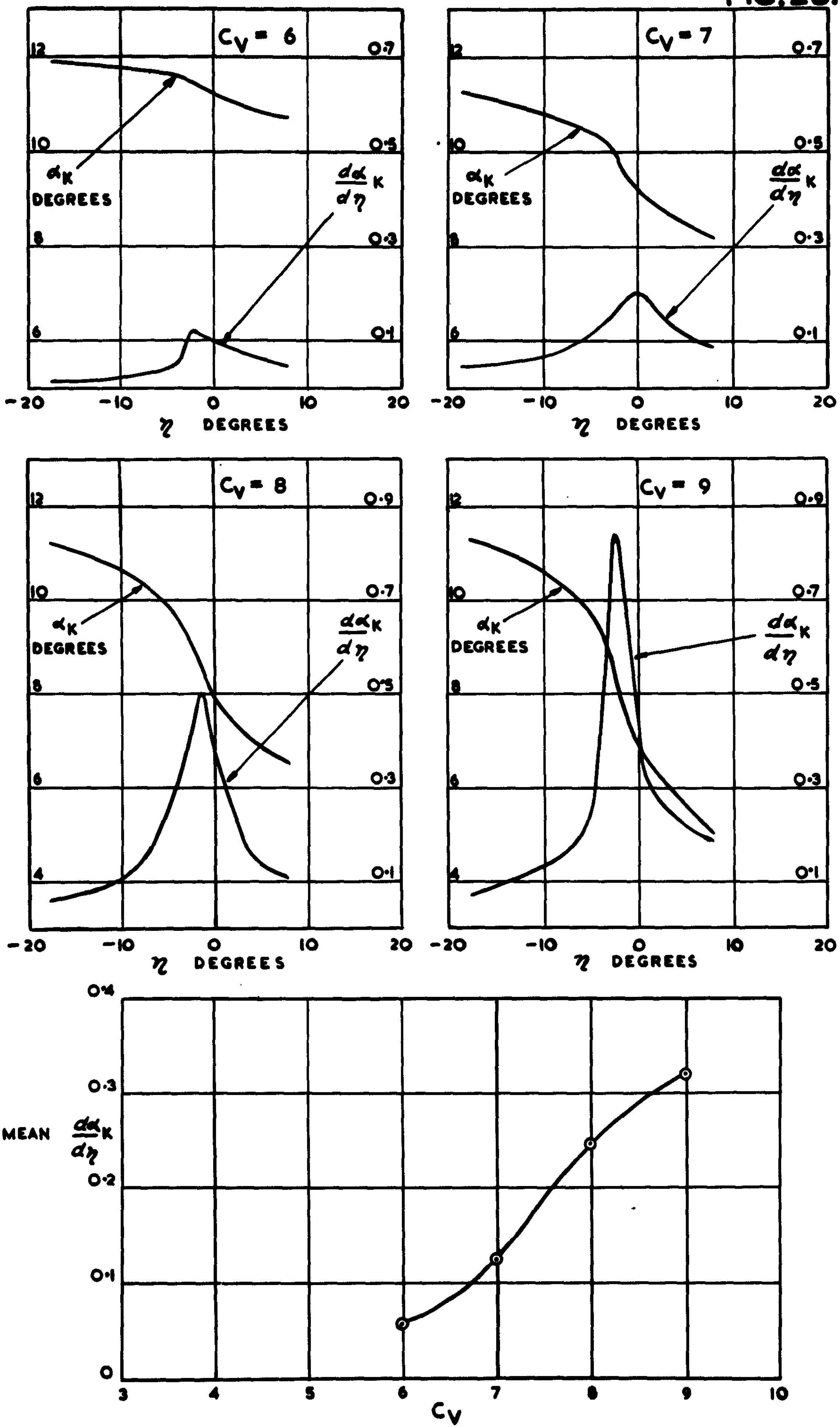
DIRECTIONAL STABILITY, $C_{\Delta_0} = 2 \cdot 75$, CONSTRAINED IN ROLL, WITH BREAKER STRIPS.

FIG. 27



MODEL A. ELEVATOR EFFECTIVENESS, $C_{A_0} = 2.75$.

FIG. 28.



MODEL A. ELEVATOR EFFECTIVENESS, $C_{\Delta_0} = 3{\cdot}00$.

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